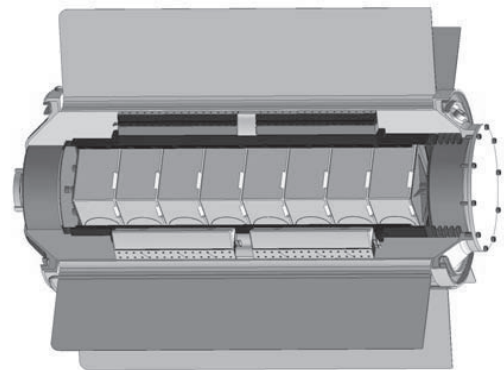
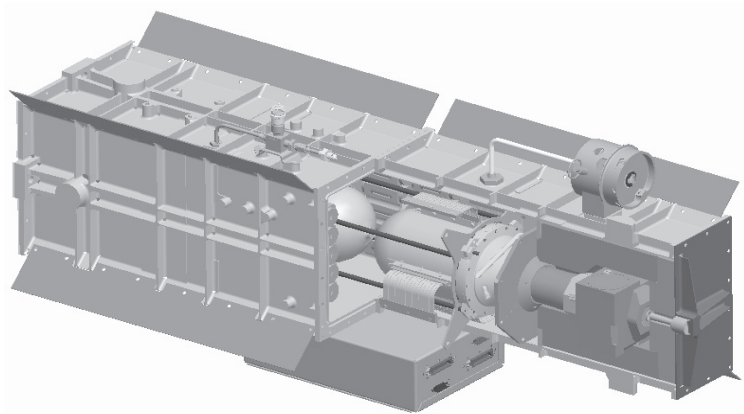


December 2005

Draft Programmatic Environmental Impact Statement for the Development of Advanced Radioisotope Power Systems



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**Science Mission Directorate
National Aeronautics and Space Administration
Washington, DC 20546**

December 2005

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ABSTRACT

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Washington, DC 20546

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DATE: December 2005

This Draft Programmatic Environmental Impact Statement (DPEIS) has been prepared by the National Aeronautics and Space Administration (NASA) in cooperation with the U.S. Department of Energy (DOE) in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), to assist the decision-making process for the development and qualification for flight of advanced Radioisotope Power Systems (RPSs). This DPEIS addresses the potential environmental impacts associated with continuing the preparations for and implementing the Proposed Action and the No Action Alternative. The proposed long-lived, reliable advanced RPS designs would enable a broad range of long-term space exploration missions and would be able to function in the environments encountered in space and on the surfaces of planets, moons, and other solar system bodies that have an atmosphere.

NASA would develop two new types of advanced RPSs; the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and the Stirling Radioisotope Generator (SRG). The MMRTG would build upon the space-flight proven passive thermoelectric technology used in the System for Nuclear Auxiliary Power-19 (SNAP-19) Radioisotope Thermoelectric Generator (RTG). The SRG utilizes a free-piston mechanism based on the Stirling thermodynamic cycle to convert heat to electricity. Both advanced RPS designs would use an enhanced version of DOE's General Purpose Heat Source (GPHS) modules, which are fueled with plutonium dioxide (consisting mostly of plutonium-238), as a heat source. NASA would also continue research and development activities focused on alternative radioisotope power systems and power converter technologies to meet future mission needs.

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EXECUTIVE SUMMARY

This *Draft Programmatic Environmental Impact Statement (DPEIS) for the Development of Advanced Radioisotope Power Systems (RPSs)* has been prepared by the National Aeronautics and Space Administration (NASA) to assist in the decision-making process as required by the National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 *et seq.*); Council on Environmental Quality Regulations for implementing the procedural provisions of NEPA (40 CFR parts 1500–1508); and NASA policies and procedures at 14 CFR subpart 1216.3.

The Proposed Action consists of two parts: (1) NASA, in cooperation with the U.S. Department of Energy (DOE), proposes to develop in the near-term and qualify for flight two advanced RPSs, the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and the Stirling Radioisotope Generator (SRG); and (2) in a parallel effort, NASA is funding related long-term research and development (R&D) of alternative radioisotope power systems and power converter technologies.

The MMRTG and the SRG would be able to satisfy a broader range of future space exploration missions than are currently possible with existing radioisotope power technologies (*e.g.*, the General Purpose Heat Source (GPHS) Radioisotope Thermoelectric Generator (RTG)). The advanced RPSs would be capable of providing long-term, reliable electrical power to spacecraft and function in the environments encountered in space and on the surfaces of planets, moons, and other solar system bodies that have an atmosphere (*e.g.*, Mars, Venus, Pluto, and two of the moons of Saturn (Titan and Enceladus)). In the follow-on chapters of this DPEIS, planets, moons, and other solar system bodies are collectively referred to as solar system bodies. The RTGs used on NASA's Galileo, Ulysses, Cassini, and the planned New Horizons missions employ the GPHS module developed by DOE, fueled by plutonium dioxide (consisting mostly of plutonium-238), as a heat source. The advanced RPS designs would generate power from the heat given off by an enhanced version of the GPHS module. It should be noted that Part (2) of the above proposal, the R&D efforts for alternative radioisotope power systems and power converter technologies, are on-going NASA activities and are addressed under both the Proposed Action and the No Action Alternative as these efforts will continue independent of the decision to be made in this PEIS. Such efforts are included to provide a full picture of future NASA RPS activities.

NASA plans to address the environmental impacts of the actions addressed in this DPEIS through a tiered NEPA process and based on existing and in-process DOE NEPA documentation for RPS-related activities. Chapter 2 of this DPEIS evaluates the alternatives considered to achieve these goals. Additional environmental documentation would be developed for the potential integrated system development (*i.e.*, full system development requiring the integration of the RPS converter with a radioisotope fuel source) and production of any new generation of space-qualified RPSs that result from long-term R&D activities as well as for the actual use of an RPS on a mission.

DOE is the sole cooperating agency in the preparation of this DPEIS.

PURPOSE AND NEED FOR ACTION

The purpose of the action addressed in this DPEIS is to develop and qualify for flight the MMRTG and the SRG to provide modular power systems for use in the environments encountered in space and on the surfaces of solar system bodies that have an atmosphere, NASA is also pursuing longer-term R&D activities directed at alternative radioisotope power systems and improvements in power converter technologies for future NASA missions, including improvements that could: further increase power conversion efficiency (thereby reducing the quantity of plutonium-238 required per unit power); reduce mass; increase specific power (power per unit mass); increase reliability, lifetime, and operability; enhance the ability to operate in harsh environments; improve multi-mission capability; and increase mission power system flexibility.

These advanced technologies, beyond the MMRTG and the SRG, may not be ready for use in space for several years. The development and production of fueled units (converters integrated with the plutonium dioxide heat source) and the use of these technologies on potential future missions would be the subject of separate NASA NEPA documentation.

NASA's future scientific exploration of the solar system is planned to include missions throughout the solar system and to the surfaces of solar system bodies. To accomplish these missions, NASA has identified a need for a variety of long-lived, reliable electric power sources that would both be capable of functioning in space as well as on the surface of solar system bodies that have an atmosphere. Current non-nuclear energy production and storage technologies available to NASA, such as batteries, solar arrays, and fuel cells are unable to deliver the reliable electric power needed for some types of missions (*e.g.*, a long lived mission to orbit an outer planet). In addition, the existing GPHS-RTG used on previous orbital missions has limited applicability on solar system bodies that have an atmosphere. The performance of the GPHS-RTG, which is designed to operate un-sealed in space vacuum, degrades in most atmospheres and does not provide the long-term operating capabilities desired for surface missions. In addition, the GPHS-RTG provides power in the range of 250 to 300 watts of electricity (W_e). NASA envisions the need for lower levels of electric power (approximately 100 W_e), and physically smaller power systems, enabling NASA to more efficiently fly smaller missions that require less power than that provided by the GPHS-RTG. The advanced RPS designs are considered modular units thus one or more of these devices could be fitted to a spacecraft for a mission requiring higher levels of electric power.

The advanced RPSs (and ultimately the power supplies resulting from the power converter technology research) would enable solar system exploration missions with substantial longevity, flexibility, and greater scientific exploration capability. The fundamental goal of these missions is to understand how our solar system became, and planetary systems in general became, habitable – and how they maintain their ability to nurture life. The goal will be achieved by answering two fundamental questions. The first is related to habitability in planetary environments, “How have specific planetary environments evolved with time, when and in what way were they habitable, and does life exist there now?” The second is associated with the planetary system architecture, “What determines the arrangement of planetary systems, what roles do the position and masses of giant planets play in the formation of habitable planets and moons?” Some possible missions would include:

- Comprehensive and detailed planetary investigations creating comparative data sets of the outer planets - Jupiter, Saturn, Uranus, Neptune and Pluto and their moons. NASA has identified three high priority missions to Europa, Titan, and Triton, which are moons of Jupiter, Saturn, and Neptune, respectively, to address habitability in planetary environments and planetary architecture. An advanced RPS could be enabling for these missions due to a combination of factors, which include their large distance from Sun, long mission duration, and high radiation environments.
- Exploration of Venus to answer the questions of habitability from the point of view of planetary architecture (How wide is the long-term habitable zone?) and habitable worlds (By what process did Venus lose its early habitability?). A long duration mission in the high temperature and high pressure Venus environment would require an advanced RPS.
- Comprehensive exploration of the surfaces and interiors of comets, possibly including returned samples to better understand the building blocks of our solar system and ingredients contributing to the origin of life.
- Expanded capabilities for surface and on-orbit exploration, and potential sample return missions to Mars and other planetary bodies to greatly improve our understanding of planetary processes, particularly those affecting the potential for life.

ALTERNATIVES EVALUATED

This DPEIS for the advanced RPSs evaluates the following alternatives:

Proposed Action

NASA, in cooperation with DOE, would develop and qualify for flight the MMRTG and the SRG. The MMRTG would build upon the spaceflight-proven passive thermoelectric power conversion technology used in the System for Nuclear Auxiliary Power-19 (SNAP-19) and would incorporate improvements to allow extended operation on the surface of solar system bodies where an atmosphere is present. For the SRG, NASA would develop a new dynamic power conversion system, a Stirling engine, that would more efficiently (than either the MMRTG or the GPHS-RTG) convert the heat from the decay of plutonium into electrical power, and therefore use less plutonium to generate comparable amounts of electrical power. The MMRTG and the SRG would provide about 100 W_e and would be able to function in the environments encountered in space and on the surface of solar system bodies that have an atmosphere. Differences in MMRTG and SRG mechanical and thermal interfaces would allow a broad range of mission specific spacecraft designs.

NASA's longer-term R&D focuses on alternative radioisotope power systems and improvements in power converter technologies, including technologies that could improve future MMRTG and SRG designs. Included in the alternative radioisotope power systems research are R&D activities for small RPSs that use the GPHS or the radioisotope heater unit (RHU) as a heat source. Development of power conversion technologies has applicability to both nuclear and non-nuclear systems. In addition, NASA would evaluate nuclear and non-nuclear power conversion systems developed independently by other organizations for their viability in space-based applications.

It is anticipated that development and test activities involving the use of radioisotopes would be performed at existing DOE sites that routinely perform similar activities. DOE currently imports from Russia plutonium dioxide needed to support NASA activities. Radioisotope fuel processing and fabrication would likely occur at existing facilities at Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico, which are currently used for the fabrication of the fuel for the GPHS modules. The advanced RPS assembly and testing would likely be performed at Idaho National Laboratory (INL), west of Idaho Falls, Idaho. Any required additional safety testing of an advanced RPS could be performed at one or more of several existing facilities; including DOE facilities such as LANL and (using fuel simulant) Sandia National Laboratory (SNL) in Albuquerque, New Mexico, or (using fuel simulant) U.S. Army facilities at Aberdeen Proving Ground (APG) in Aberdeen, Maryland.

Activities not requiring the use of radioisotopes and associated with the development, testing, and verification of the MMRTG and SRG power conversion systems could be performed at several existing facilities including NASA facilities (such as the Glenn Research Center (GRC) at Lewis Field, Cleveland, Ohio and the Jet Propulsion Laboratory (JPL), Pasadena, California); and at several commercial facilities (Pratt & Whitney Rocketdyne, Canoga Park, California; Teledyne Energy Systems, Hunt Valley, Maryland; Infinia Corporation, Kennewick, Washington; Lockheed Martin Commercial Space Systems, Newtown, Pennsylvania; and Lockheed Martin Space Systems Company, King of Prussia, Pennsylvania).

No Action Alternative

Under the No Action Alternative, NASA would discontinue efforts for the development of the MMRTG and the SRG. NASA would continue to consider the use of currently available RPSs, such as the GPHS-RTG, for future exploration missions. However, DOE's GPHS-RTG production line is no longer operative, including the Silicon/Germanium (SiGe) thermocouple manufacturing operations. It may be possible to construct a limited number (one or two) of GPHS-RTGs from existing parts inventories, but longer term reliance on this technology would require the reactivation of these production capabilities, including re-establishing vendors for GPHS-RTG components, which could involve a substantial financial investment. In the follow-on Chapters of this DPEIS, reference to reactivating the GPHS-RTG production line is inclusive of reactivating the Si/Ge manufacturing operations and re-establishing the supply vendors.

NASA will continue to pursue the R&D of alternative radioisotope power systems and power converter technologies as described for the Proposed Action. However in the near term, as a result of discontinuing further R&D of the MMRTG and SRG, NASA would not develop an RPS in the 100 W_e class, nor one that is compatible with operating on solar system bodies where an atmosphere is present. Discontinuing long-term R&D efforts for this class of RPS, in particular the SRG, would end an effort that could lead to a significant reduction in plutonium fuel usage.

ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION AND THE NO ACTION ALTERNATIVE

Proposed Action

The principal near and mid-term activities associated with the Proposed Action and potential environmental impacts include:

Development of 100 W_e capable MMRTG and SRG units and demonstration of performance in flight qualified, fueled systems.

Demonstration of power conversion technology through full power testing using non-radioactive heat sources. These types of activities have been conducted for the GPHS-RTG used for the Galileo, Ulysses, and Cassini missions, and the activities and environmental impacts are well understood. These operations are small-scale laboratory activities that do not, with the exception of qualification of fueled units, involve radiological materials. Only small quantities of hazardous materials might be involved. The potential for impacts on worker health, public health, and the environment is small.

Plutonium-Fueled Clad Production at LANL, including transportation of plutonium dioxide to LANL; producing fueled clads for RPSs; and disposal of plutonium contaminated waste. Production of plutonium fuel at LANL, including receiving shipments of plutonium dioxide, conversion into pellets, and encapsulation has been an ongoing activity for more than a decade. The fueled clads needed for the MMRTG and SRG would be identical to those currently being prepared for the GPHS-RTG for NASA's planned New Horizons mission and any that could be prepared for other NASA missions under the No Action Alternative. The potential impacts of these LANL operations have been well characterized in previous DOE NEPA documents. Under both normal operations and accidents, the plutonium dioxide would be confined within the building such that the amount that could be released through the building filtration system would be negligible, with no anticipated health impacts.

Ongoing RTG Operations at INL, including fueling the GPHS module with fueled clads and integrating the fueled GPHS modules with the advanced converters, and qualification and acceptance testing. The worker and public health impacts, and other environmental impacts of assembly of the GPHS modules from loading the fueled clads and mating the GPHS modules with the converter assembly at INL have been well characterized in previously prepared DOE NEPA documents. In the fueled clads received from LANL, the plutonium dioxide is encapsulated and none of the operations at INL would threaten the integrity of the clads. These operations would be similar to past RTG assembly and test operations at the DOE Mound facility. The action addressed in this DPEIS would fall within the normal realm of operations at both INL and LANL and would not exacerbate the existing environmental baseline.

Advanced RPS Testing Activities, including impact testing of RPSs with low activity level simulants instead of plutonium fuel.

The impacts of past testing activities associated with the GPHS-RTGs have been well documented in previously prepared DOE NEPA documents. These safety impact tests used non-plutonium materials including depleted uranium to simulate the damage that might be done to the fuel under accident conditions. Future tests, if needed, would likely be similar to past tests and present negligible threats to workers and public (resulting in no expected health impacts) and the environment.

Currently, DOE is considering plans to consolidate operations at its INL facility for the domestic production of plutonium; the NEPA process for this action is on-going (DOE 2005a). Three alternatives are being evaluated by DOE for this purpose: the Consolidation Alternative

(consolidate all RPS activities at INL); the Consolidation with Bridge Alternative (maintain *status quo* until INL facilities become operative); and the No Action Alternative (maintain *status quo*). NASA holds no stake in the decision ultimately taken by DOE related to its long-term production of plutonium-238. NASA's Proposed Action in this DPEIS is independent of the Consolidation EIS (DOE 2005a) alternative selected by the DOE.

Over the longer term, if NASA's proposed RPS development activities are successful, then the following activities would be reasonably anticipated:

- MMRTG and SRG flight unit production and launch-area preparations, including final preparations at the Launch Area Facility; launch of MMRTG and SRG units; and post-launch operation of spacecraft using RPS.
- Full system development of alternative radioisotope power systems, including the integration of RPS converters with radioisotope fuel sources, potentially utilizing advanced power conversion technologies

Each of these potential follow-on activities has the potential for environmental impacts that could be of concern. In some cases, such as MMRTG and SRG unit launch or on-orbit activities, the principal concern is the potential for accidents resulting in the release of radiological material. These potential follow-on activities are beyond the scope of this DPEIS and would be addressed in future NASA NEPA documentation. This DPEIS does, however, discuss each of these types of potential follow-on activities to the extent practicable at this time.

NASA's on-going long-term R&D activities for alternative power systems and advanced power conversion technologies are small-scale, laboratory activities, performed in accordance with applicable environmental regulations. No radioisotopes are involved and only small quantities of hazardous materials might be involved. The potential for impacts on worker health, public health, and the environment from these R&D activities is small.

No Action Alternative

Under the No Action Alternative, the production of GPHS-RTGs would still continue to support future NASA missions (although these would not include 1) long-term missions in planetary atmospheres, or 2) missions designed for a power level of approximately 100W_e). However, the GPHS-RTG production line would have to be reactivated. Re-establishing this capability would not have an affect on on-going DOE operations. However, an environmental review may be needed. Impacts to plutonium workers and potential impacts to the public health and the environment at LANL would be consistent with those associated with the Proposed Action. Worker and public health impacts at LANL would not pose substantial threats. Production of plutonium fuel at LANL and assembly of GPHS modules and RTGs would continue at INL.

As with LANL, impacts to workers and the postulated impacts to the public and the environment at INL would be consistent with those associated with the Proposed Action. Depending on NASA requirements, some missions may not be possible without RPSs that function effectively in planetary atmospheres. Potential impacts of NASA's on-going R&D activities will be as described for the Proposed Action.

The ultimate level of plutonium production and use, and consequently the environmental impacts, under the No Action Alternative or the Proposed Action would be dependent upon the

number of missions that ultimately select a GPHS-RTG or an advanced RPS as a power supply. DOE's production of plutonium and RPSs for purposes other than for NASA will continue irrespective of NASA's actions.

SUMMARY OF NEPA ACTIVITIES

This *Draft Programmatic EIS (DPEIS) for the Development of Advanced Radioisotope Power Systems* was initiated on April 24, 2004 with publication of NASA's Notice of Intent (NOI) in the *Federal Register* (69 FR 21867). Publication of the NOI opened the scoping period during which comments and environmental concerns with NASA's proposal were solicited from interested agencies, organizations, and individuals. The scoping period, originally scheduled to close on June 4, 2004, was extended by NASA until July 30, 2004. All comments received were considered in the development of this DPEIS. NASA has formally released this DPEIS for public review via publication in the *Federal Register* of the Notice of Availability (NOA) by the U.S. Environmental Protection Agency (EPA). This DPEIS has been distributed in hardcopy and is also available electronically via the Worldwide Web at the address noted in the NOA. This DPEIS is being made available to interested agencies, organizations, and individuals for review and comment for a minimum of 45 days.

Upon completion of the public review and comment period, NASA will consider and prepare appropriate responses to all comments received compiling all comments and responses in an Appendix. In addition, NASA will revise and update the DPEIS as appropriate resulting in a *Final Programmatic Environmental Impact Statement (FPEIS) for the Development of Advanced Radioisotope Power Systems*. The FPEIS will then be made available to all interested parties for a minimum of 30 days. NASA will formally release the FPEIS to all interested agencies, organizations, and individuals via publication in the *Federal Register* of the NOA by the U.S. EPA. The FPEIS will also be distributed in hardcopy and made available electronically via the Worldwide Web at an address noted in the NOA. No sooner than 30-days following publication of the NOA NASA will prepare the NEPA decision document – the Record of Decision (ROD). The ROD will be posted on the Worldwide Web and made available to all interested parties upon request, formally completing the NEPA process.

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TABLE OF CONTENTS

ABSTRACT.....	iii
EXECUTIVE SUMMARY	v
TABLE OF CONTENTS.....	xiii
LIST OF FIGURES	xviii
LIST OF TABLES.....	xviii
ABBREVIATIONS AND ACRONYMS	xix
COMMON METRIC/BRITISH SYSTEM EQUIVALENTS.....	xxii
1 PURPOSE AND NEED FOR ACTION.....	1-1
1.1 BACKGROUND	1-1
1.2 PURPOSE OF THE ACTION	1-2
1.3 NEED FOR THE ACTION	1-3
1.4 NEPA PLANNING AND SCOPING ACTIVITIES	1-4
1.5 NEPA ACTIVITIES RELATED TO THE PROPOSED ACTION	1-5
2 DESCRIPTION AND COMPARISON OF ALTERNATIVES	2-1
2.1 DESCRIPTION OF THE PROPOSED ACTION	2-2
2.1.1 Facilities Involved.....	2-3
2.1.2 RPS Overview.....	2-4
2.1.2.1 Background	2-4
2.1.2.2 MMRTG and SRG Development.....	2-9
2.1.3 Research, Development and Fabrication of the MMRTG	2-11
2.1.3.1 MMRTG Background	2-11
2.1.3.2 MMRTG Development	2-13
2.1.3.3 Technology Transition to Flight for MMRTG	2-14
2.1.4 Research, Development and Fabrication of the SRG	2-14
2.1.4.1 SRG Background.....	2-14
2.1.4.2 SRG Development.....	2-15
2.1.4.3 Technology Transition to Flight for SRG	2-16
2.1.5 Plutonium-238 Importation and Transportation to LANL.....	2-16

2.1.6	Plutonium Dioxide Fueled Clad Production at LANL	2-17
2.1.7	Advanced RPS Operations at INL	2-17
2.1.8	Advanced RPS Safety Testing.....	2-17
2.1.9	End Use of Advanced RPSs.....	2-18
2.2	DESCRIPTION OF THE NO ACTION ALTERNATIVE	2-18
2.3	ON-GOING NASA RESEARCH & DEVELOPMENT ACTIVITIES	2-19
2.3.1	Radioisotope Power Conversion Technology NASA Research Announcements.....	2-19
2.3.2	Converter Technology Development at NASA Facilities	2-21
2.3.3	Facilities Involved.....	2-22
2.4	ALTERNATIVES CONSIDERED BUT NOT EVALUATED FURTHER.....	2-22
2.4.1	Alternative Advanced RPS Concepts Including Developing only the MMRTG or the SRG	2-22
2.4.2	Modified GPHS-RTG	2-23
2.4.3	Develop Only Non-Radioisotope Power Systems	2-24
2.5	COMPARISON OF ALTERNATIVES INCLUDING THE NO ACTION ALTERNATIVE	2-25
3	DESCRIPTION OF THE AFFECTED ENVIRONMENT	3-1
3.1	LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NEW MEXICO...	3-3
3.1.1	Land Resources.....	3-3
3.1.2	Air Resources.....	3-3
3.1.3	Water Resources	3-4
3.1.4	Ambient Noise	3-5
3.1.5	Geology and Soils	3-5
3.1.6	Biological Resources	3-5
3.1.7	Socioeconomics	3-6
3.1.8	Cultural Resources	3-6
3.1.9	Hazardous and Radioactive Waste.....	3-6
3.1.10	Transportation of Radioisotope Components	3-7
3.1.11	Human Health	3-7

3.2	IDAHO NATIONAL LABORATORY, IDAHO FALLS, IDAHO.....	3-8
3.2.1	Land Resources	3-8
3.2.2	Air Resources.....	3-8
3.2.3	Water Resources	3-9
3.2.4	Ambient Noise	3-9
3.2.5	Geology and Soils.....	3-10
3.2.6	Biological Resources	3-10
3.2.7	Socioeconomics	3-11
3.2.8	Cultural Resources.....	3-11
3.2.9	Hazardous and Radioactive Waste.....	3-11
3.2.10	Transportation of Radioisotope Components	3-12
3.2.11	Human Health	3-12
3.3	SANDIA NATIONAL LABORATORY, ALBUQUERQUE, NEW MEXICO.....	3-12
3.3.1	Land Resources.....	3-12
3.3.2	Air Resources.....	3-13
3.3.3	Water Resources	3-13
3.3.4	Ambient Noise	3-14
3.3.5	Geology and Soils.....	3-14
3.3.6	Biological Resources	3-14
3.3.7	Socioeconomics	3-15
3.3.8	Cultural Resources.....	3-15
3.3.9	Hazardous and Radioactive Waste.....	3-15
3.3.10	Transportation of Radioisotope Components	3-15
3.3.11	Human Health	3-16
3.4	ABERDEEN PROVING GROUND, ABERDEEN, MARYLAND.....	3-16
3.4.1	Land Resources.....	3-16
3.4.2	Air Resources.....	3-17
3.4.3	Water Resources	3-17
3.4.4	Ambient Noise	3-18
3.4.5	Geology and Soils.....	3-18

3.4.6	Biological Resources	3-19
3.4.7	Socioeconomics	3-19
3.4.8	Cultural Resources	3-20
3.4.9	Hazardous and Radioactive Material	3-20
3.5	GLENN RESEARCH CENTER AT LEWIS FIELD, CLEVELAND, OHIO	3-20
3.5.1	Land Resources	3-20
3.5.2	Air Resources	3-21
3.5.3	Water Resources	3-21
3.5.4	Ambient Noise	3-22
3.5.5	Geology and Soils	3-22
3.5.6	Biological Resources	3-23
3.5.7	Socioeconomics	3-23
3.5.8	Cultural Resources	3-23
3.5.9	Hazardous and Radioactive Materials	3-24
3.6	JET PROPULSION LABORATORY, PASADENA, CALIFORNIA	3-24
3.6.1	Land Resources	3-24
3.6.2	Air Resources	3-24
3.6.3	Water Resources	3-25
3.6.4	Ambient Noise	3-25
3.6.5	Geology and Soils	3-26
3.6.6	Biological Resources	3-26
3.6.7	Socioeconomics	3-27
3.6.8	Cultural Resources	3-27
3.6.9	Hazardous and Radioactive Material	3-27
3.7	COMMERCIAL FACILITIES	3-27
4	ENVIRONMENTAL CONSEQUENCES	4-1
4.1	ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION	4-1
4.1.1	Environmental Impacts of Research, Development and Production of MMRTGs	4-3

4.1.2	Environmental Impacts of Research, Development, and Production of SRGs	4-4
4.1.3	Environmental Impacts of Plutonium-238 Transportation to LANL	4-5
4.1.4	Environmental Impacts of Plutonium-238 Fuel Clad Production at LANL	4-6
4.1.5	Environmental Impacts of RPS Operations at INL.....	4-7
4.1.6	Environmental Impacts of Advanced RPS Safety Testing	4-9
4.1.7	Environmental Considerations Associated with End Use of the Advanced RPS	4-9
4.1.8	Environmental Justice	4-11
4.2	ENVIRONMENTAL IMPACTS OF THE NO ACTION ALTERNATIVE	4-11
4.2.1	Environmental Considerations Associated with End Use of GPHS-RTG.....	4-11
4.2.2	Environmental Justice	4-12
4.3	ENVIRONMENTAL IMPACTS OF ADVANCED CONVERTER DEVELOPMENT	4-12
4.4	CUMULATIVE IMPACTS.....	4-13
4.5	ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED.....	4-15
4.6	INCOMPLETE OR UNAVAILABLE INFORMATION	4-16
4.7	RELATIONSHIP BETWEEN SHORT-TERM USES OF THE HUMAN ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY	4-16
4.8	IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES	4-16
4.9	ENVIRONMENTAL COMPLIANCE AT ADVANCED RPS DEVELOPMENT, FABRICATION, ASSEMBLY, AND TEST SITES	4-16
5	LIST OF PREPARERS.....	5-1
6	AGENCIES AND INDIVIDUALS CONSULTED	6-1
7	INDEX	7-1
8	REFERENCES	8-1
	APPENDIX A: GLOSSARY OF TERMS	A-1

LIST OF FIGURES

Figure 2-1. RPS Schedule and Milestones.....	2-2
Figure 2-2. GPHS Module	2-8
Figure 2-3. Multi-Mission Radioisotope Thermoelectric Generator	2-11
Figure 2-4. Stirling Radioisotope Generator.....	2-12
Figure 2-5. Potential RHU-Based Smaller Power Source	2-20
Figure 2-6. Potential RHU-Module Heat Source for RHU-Based Smaller Power Source of Figure 2-5	2-20
Figure 3-1. Locations of Facilities.....	3-2

LIST OF TABLES

Table 2-1. U.S. Missions Using Radioisotope Power and Heat Sources.....	2-5
Table 2-2. Enhanced GPHS Mass Breakdown (Anticipated).....	2-8
Table 2-3. Top-level Requirements for MMRTG and SRG	2-10
Table 2-4. Comparison of Attributes Between the MMRTG and the SRG.....	2-13
Table 2-5. Planned MMRTG and SRG Test Activities	2-15
Table 2-6. NASA Research for Radioisotope Power Conversion Technology	2-21
Table 2-7. Comparison of Potential Impacts of Alternatives – Programmatic Perspective	2-26
Table 2-8. Comparison of Potential Impacts of Alternatives – Environmental Media	2-29
Table 3-1. Advanced RPS Activities and Associated Facilities	3-2

ABBREVIATIONS AND ACRONYMS

A		E	
AC	alternating current	EA	Environmental Assessment
ac	acre	EIS	Environmental Impact Statement
AMTEC	Alkali Metal Thermal to Electric Converter	EMC	electromagnetic compatibility
ANL-W	Argonne National Laboratory – West	EMI	electromagnetic interference
APG	Aberdeen Proving Grounds	EO	Executive Order
ATR	Advanced Test Reactor	EPA	U. S. Environmental Protection Agency
		ERD	Environmental Resources Document
B		F	
BASE	beta alumina solid electrolyte	° F	degrees Fahrenheit
BOM	beginning of mission	FONSI	Finding of No Significant Impact
C		FR	Federal Register
° C	degrees Celsius	ft	foot/feet
CAA	Clean Air Act	FWS	Fish and Wildlife Service
CBCF	Carbon Bonded Carbon Fiber	FY	fiscal year
CCAFS	Cape Canaveral Air Force Station		
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	G	
CFR	Code of Federal Regulations	g	gram
cm	centimeter	Ga	gallium
CO	carbon monoxide	gal	gallon
CO ₂	carbon dioxide	Ge	germanium
CWA	Clean Water Act	GPHS	General Purpose Heat Source
		GPHS-RTG	General Purpose Heat Source-Radioisotope Thermoelectric Generator
		GRC	Glenn Research Center
		GSP	Gross State Product
D		H	
dba	a-weighted decibels	ha	hectare
DC	direct current	HEPA	High Efficiency Particulate Air (filter)
DoD	Department of Defense	HFIR	High Flux Isotope Reactor
DOE	Department of Energy	hr	hour
DOT	Department of Transportation	HS/RPS	Heat Source/Radioisotope Power System
DPEIS	Draft Programmatic Environmental Impact Statement	Hz	hertz

I		NASA	National Aeronautics and Space Administration
ICUZ	Installation Compatible Use Zone	NEPA	National Environmental Policy Act
in	inch	NOA	Notice of Availability
INRMP	Integrated Natural Resources Management Plan	NOI	Notice of Intent
INEEL	Idaho National Engineering and Environmental Laboratory	NO ₂	nitrogen dioxide
INL	Idaho National Laboratory	NO _x	oxides of nitrogen
INSRP	Interagency Nuclear Safety Review Panel	NPDES	National Pollutant Discharge Elimination System
J		NPL	National Priority List
JPL	Jet Propulsion Laboratory	NRA	NASA Research Announcement
K		NRHP	National Register of Historic Places
KAFB	Kirkland Air Force Base	O	
kg	kilogram	ORNL	Oak Ridge National Laboratory
km	kilometer	OSTP	Office of Science and Technology Policy
KSC	Kennedy Space Center	oz	ounce
L		O ₃	ozone
l	liter	P	
lb	pound	Pb	lead
LANL	Los Alamos National Laboratory	PCB	polychlorinated biphenyl
M		PM ₁₀	Particulate Matter less than 10 microns in size
m	meter	PM _{2.5}	Particulate Matter less than 2.5 microns in size
m ³	cubic meter	Pu	Plutonium
MER	Mars Exploration Rover	Pu-238	Plutonium-238
MHW	Multi-Hundred Watt	R	
mi	mile	RCRA	Resource Conservation and Recovery Act
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator	R&D	research and development
mph	miles per hour	REDC	Radiochemical Engineering Development Center
mrem	millirem	RHU	Radioisotope Heater Unit
mw	milliwatts	RLWTF	Radioactive Liquid Waste Treatment Facility
N		ROD	Record of Decision
NAAQS	National Ambient Air Quality Standards	RPS	Radioisotope Power System

RTG	Radioisotope Thermoelectric Generator		Y
	S	yr	year
SAR	Safety Analysis Report		
SCAB	South Coast Air Basin		
SCAQMD	South Coast Air Quality Management District		
Sb	antimony		
SER	Safety Evaluation Report		
SGT	SafeGuards Transport		
Si	silicon		
Sn	tin		
SNAP	System for Nuclear Auxiliary Power		
SNL	Sandia National Laboratory		
SO ₂	sulfur dioxide		
SRG	Stirling Radioisotope Generator		
SST	safe, secure trailer		
STS	Secure Transportation System		
SWEIS	Site-wide Environmental Impact Statement		
	T		
TA	Technical Area		
TAGS	tellurides of antimony, germanium, and silver		
Te	tellurium		
TPV	Thermo-Photovoltaic		
TRU	transuranic (waste)		
	U		
U.S.	United States of America		
U.S.C.	United States Code		
UXO	Unexploded ordnance		
	V		
VAFB	Vandenberg Air Force Base		
	W		
W _e	watts – electric		
W _{th}	watts – thermal		

COMMON METRIC/BRITISH SYSTEM EQUIVALENTS

Length

1 centimeter (cm) = 0.3937 inch (in)	1 in = 2.54 cm
1 centimeter = 0.0328 foot (ft)	1 ft = 30.48 cm
1 meter (m) = 3.2808 feet	1 ft = 0.3048 m
1 meter = 0.0006 mile (mi)	1 mi = 1609.3440 m
1 kilometer (km) = 0.6214 mile	1 mi = 1.6093 km
1 kilometer = 0.53996 nautical mile (nmi)	1 nmi = 1.8520 km
1 mi = 0.87 nmi	1 nmi = 1.15 mi

Area

1 square centimeter (cm ²) = 0.1550 square inch (in ²)	1 in ² = 6.4516 cm ²
1 square meter (m ²) = 10.7639 square feet (ft ²)	1 ft ² = 0.09290 m ²
1 square kilometer (km ²) = 0.3861 square mile (mi ²)	1 mi ² = 2.5900 km ²
1 hectare (ha) = 2.4710 acres (ac)	1 ac = 0.4047 ha
1 hectare (ha) = 10,000 square meters (m ²)	1 m ² = .0001 ha

Volume

1 cubic centimeter (cm ³) = 0.0610 cubic inch (in ³)	1 in ³ = 16.3871 cm ³
1 cubic meter (m ³) = 35.3147 cubic feet (ft ³)	1 ft ³ = 0.0283 m ³
1 cubic meter = 1.308 cubic yards (yd ³)	1 yd ³ = 0.76455 m ³
1 liter (l) = 1.0567 quarts (qt)	1 qt = 0.9463264 l
1 liter = 0.2642 gallon (gal)	1 gal = 3.7845 l
1 kiloliter (kl) = 264.2 gal	1 gal = 0.0038 kl

Weight

1 gram (g) = 0.0353 ounce (oz)	1 oz = 28.3495 g
1 kilogram (kg) = 2.2046 pounds (lb)	1 lb = 0.4536 kg
1 metric ton (mt) = 1.1023 tons	1 ton = 0.9072 mt

Energy

1 joule = 0.0009 British thermal unit (BTU)	1 BTU = 1054.18 joule
1 joule = 0.2392 gram-calorie (g-cal)	1 g-cal = 4.1819 joule

Pressure

1 newton/square meter (N/m ²) = 0.0208 pound/square foot (psf)	1 psf = 48 N/m ²
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Force

1 newton (N) = 0.2248 pound-force (lb-f)	1 lb-f = 4.4478 N
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Radiation

1 becquerel (Bq) = 2.703×10^{-11} curies (Ci)

1 sievert (Sv) = 100 rem

1 Ci = 3.70×10^{10} Bq

1 rem = 0.01 Sv

Scientific Notation

10^{-9} = 0.000000001 (1 in 1 billion)

10^{-8} = 0.00000001 (1 in 100 million)

10^{-7} = 0.0000001 (1 in 10 million)

10^{-6} = 0.000001 (1 in 1 million)

10^{-5} = 0.00001

10^{-4} = 0.0001

10^{-3} = 0.001

10^{-2} = 0.01

10^{-1} = 0.1

10^0 = 1

10^1 = 10

10^2 = 100

10^3 = 1,000

10^4 = 10,000

10^5 = 100,000

10^6 = 1,000,000 (1 million)

10^7 = 10,000,000 (10 million)

10^8 = 100,000,000 (100 million)

10^9 = 1,000,000,000 (1 billion)

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1 PURPOSE AND NEED FOR ACTION

This Draft Programmatic Environmental Impact Statement (DPEIS) for the development of advanced Radioisotope Power Systems (RPSs) has been prepared by the National Aeronautics and Space Administration (NASA) to assist in the decision-making process as required by the National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 *et seq.*); Council on Environmental Quality Regulations for implementing the procedural provisions of NEPA (40 CFR parts 1500–1508); and NASA policies and procedures at 14 CFR subpart 1216.3. NASA, in cooperation with U.S. Department of Energy (DOE), proposes to develop two types of advanced RPSs, the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and the Stirling Radioisotope Generator (SRG) to satisfy a wide range of future space exploration mission requirements. The advanced RPSs would be capable of functioning in space and on the surfaces of planets, moons, and other solar system bodies that have an atmosphere (*e.g.*, Mars, Venus, Pluto, and two of the moons of Saturn (Titan and Enceladus)). In the following sections of this chapter, planets, moons, and other solar systems bodies are collectively referred to as solar system bodies.

NASA plans to address the environmental impacts of the development of advanced RPSs through a tiered NEPA process and based on existing and in-process DOE NEPA documentation for RPS-related activities. This DPEIS addresses (1) development for launch and use in space of the MMRTG and the SRG to provide modular power systems, and (2) related long-term research and development (R&D) of alternative radioisotope power systems and power converter technologies. These long-term R&D activities could include, but not necessarily be limited to improvements to further increase the versatility of future RPS designs, expanding their capability and the environments in which they can operate. The long-term R&D activities are also expected to include work on RPS designs with smaller electric outputs and efforts to reduce the mass of power conversion systems to further improve specific power (watts of electrical power per unit of mass). Additional environmental documentation would be developed for the potential integrated system development (*i.e.*, full system development requiring the integration of the RPS converter with a radioisotope fuel source) and production of any new generation of space-qualified RPSs that results from the related long-term R&D of technologies (*e.g.*, more efficient systems or systems producing smaller electrical power output). Actual use of the MMRTG or SRG for spacecraft would be the subject of separate mission-specific NEPA documentation.

DOE is the sole cooperating agency in the preparation of this DPEIS.

1.1 BACKGROUND

Radioisotope Thermoelectric Generators (RTGs) of various types have been launched on 24 U.S. space missions, including: Apollo 11 through 17, Pioneer, Viking, Voyager, and the Galileo, Ulysses, and Cassini missions. The generator technology developed by DOE has resulted in several radioisotope power systems, evolving from the Systems for Nuclear Auxiliary Power (SNAP) series of RTGs, to the Multi-Hundred Watt (MHW)-RTG, and most recently, to the General Purpose Heat Source-RTG (GPHS-RTG) used for the Galileo, Ulysses, Cassini, and the planned New Horizons missions. The GPHS-RTG consists of two major functional components, the thermoelectric converter and a stack of 18 individual GPHS modules. The GPHS module consists of plutonium dioxide fuel pellets encased in iridium clads and a series of protective shells designed to prevent damage to the clad during inadvertent reentry and impact. Each

individual GPHS module produces roughly 250 watts of heat, or thermal watts (W_{th}). The thermoelectric power converter used in recent missions consisted of 572 silicon germanium (SiGe) thermoelectric couples, which convert decay heat from the plutonium directly into electricity. When first fueled for the Cassini mission, this type of converter produced about 300 watts of electric power (W_e) with a converter efficiency between 6 and 7 % (Lockheed Martin 1997).

The GPHS-RTG was developed by DOE starting in the late 1970s and has been used by NASA on science missions, principally orbital observations of various bodies in the solar system (most recently, the Cassini mission to Saturn). These GPHS-RTGs have had and are continuing to have tremendous success with very high, long-term reliability for those missions. The power converters, however, were not designed to perform effectively for extended durations on solar system bodies with an atmosphere nor for missions that require power levels less than 200 W_e .

The advanced RPSs would be actively considered for use on future NASA missions, in part, because of their versatility (including the ability to operate on surface of solar system bodies with an atmosphere), their ability to operate continuously, independent of orientation to and distance from the Sun, and their modularity. The advanced RPS designs are proposed in order to provide the capability for extended operation on the surface of solar system bodies that have an atmosphere as well as in the environments encountered in space. Under the Proposed Action, two proposed advanced RPS designs, utilizing different power conversion technologies, would be developed. The MMRTG converter design would be based on thermocouple technology used in the SNAP-19 RTG, which was used successfully on the Viking Mars Landers and the Pioneer spacecraft in the 1970s. The MMRTG would build upon this spaceflight-proven passive thermoelectric power conversion technology. The SRG would incorporate a dynamic power conversion system based upon a Stirling engine that would more efficiently, compared to the MMRTG or the GPHS-RTG, convert the heat from the decay of plutonium into electrical power. Although NASA has used Stirling engines previously in space (*e.g.*, cryocoolers), NASA has not used a Stirling power conversion system for space applications. Both the MMRTG and the SRG would use an enhanced version of the GPHS. This enhanced GPHS is the result of DOE's continuing efforts to further improve the GPHS safety performance.

1.2 PURPOSE OF THE ACTION

NASA's future scientific exploration is planned to include missions throughout the solar system and missions to the surfaces of planets, moons, and other solar system bodies. Many of these missions can not be accomplished or would have substantially limited applicability with current energy production and storage technologies available to NASA, such as batteries, solar arrays, fuel cells, and the existing space flight qualified radioisotope power system (*i.e.*, GPHS-RTG). NASA envisions missions needing power generating capability with substantial longevity and flexibility to enable greater scientific exploration capabilities. The purpose of the action is to develop advanced power systems, specifically advanced RPSs, that would enable this broad range of missions. NASA is proposing to develop advanced RPS designs that would ultimately enhance mission capability by 1) providing long term reliable power on the surface of solar system bodies with atmospheres, 2) providing power systems with enhanced modularity over existing systems thus enabling a wider range of mission types than previously possible, and 3) boosting the efficiency of RPSs. These RPSs would be long-lived, reliable electric power systems capable of producing on the order of 100 W_e both in space and in the environments

encountered on the surface of solar system bodies that have an atmosphere. More than one RPS could be integrated with a spacecraft to provide higher power levels.

NASA is also pursuing research efforts directed at longer-term improvements to existing power conversion technologies for RPSs and the development of new power conversion technologies. Desired improvements would be increased system specific power; increased efficiencies for power conversion technologies; increased reliability, lifetime, and operability; greater power system flexibility enabling use in more places in space and on solar system bodies; improved ability to operate in extreme environments and improvements in modularity. One area of research into new power conversion system technology addresses the development of smaller power systems (milliwatt to several watt sized systems) that could provide additional flexibility and modularity for mission applications. While the new power conversion systems could be based on the GPHS module or the radioisotope heater unit (RHU), the power converter development efforts could lead to technologies that are applicable to both nuclear and non-nuclear systems. The results from this research may not be ready for use in space for several years, but may ultimately result in the identification of improved system designs. The potential development of these technologies into final system designs is not addressed in this DPEIS and would be the subject of future NASA NEPA documentation.

1.3 NEED FOR THE ACTION

In the past, NASA mission electric power needs were based upon supporting mission requirements that resulted in the use of relatively large spacecraft (*e.g.*, the Cassini mission). As NASA's vision for future exploration has evolved, these mission power needs have also evolved. Now NASA's future scientific exploration of the solar system is planned to include missions throughout the solar system and missions to the surface of solar system bodies. The fundamental goal of these solar system exploration missions is to understand how our solar system became, and planetary systems in general became, habitable – and how they maintain their ability to nurture life. The goal will be achieved by answering two fundamental questions. The first is related to habitability in planetary environments, “How have specific planetary environments evolved with time, when and in what way were they habitable, and does life exist there now?” The second is associated with the planetary system architecture, “What determines the arrangement of planetary systems, what roles do the position and masses of giant planets play in the formation of habitable planets and moons?” Some missions would need power systems that can provide long term survivability on the surface of solar system bodies that have an atmosphere and allow surface mobility (*e.g.*, rovers) by being lighter and more compact than the current GPHS-RTG. Such missions could include:

- Comprehensive and detailed planetary investigations creating comparative data sets of the outer planets - Jupiter, Saturn, Uranus, Neptune, and Pluto, and their moons. The NASA has identified three high priority missions to Europa, Titan, and Triton, which are moons of Jupiter, Saturn, and Neptune, respectively, to address habitability in planetary environments and planetary architecture. An advanced RPS could be enabling for these missions due to a combination of factors, which include their large distance from the Sun, long mission duration, and high radiation environments.
- Exploration of Venus to answer the questions of habitability from the point of view of planetary architecture (How wide is the long-term habitable zone?) and habitable worlds (By

what process did Venus lose its early habitability?). A long duration mission in the high temperature and high pressure Venus environment would require an advanced RPS.

- Comprehensive exploration of the surfaces and interiors of comets, possibly including returned samples to better understand the building blocks of our solar system and ingredients contributing to the origin of life.
- Expanded capabilities for surface missions, on-orbit exploration, and potential sample return missions to the Moon, Mars and other solar system bodies. Such capabilities could greatly improve our understanding of planetary processes, particularly those affecting the potential for life.

Many of these missions could not be accomplished with current energy production and storage technologies available to NASA, such as batteries, solar arrays, fuel cells, and the existing GPHS-RTG. The GPHS-RTG, designed to operate un-sealed in space vacuum, used on previous orbital missions has limited applicability on surfaces of solar system bodies where an atmosphere is present. The performance of the converter, specifically the thermocouples and the multi-foil insulation, degrades in most atmospheres and does not provide the long-term operating capabilities desired for these surface missions. In addition, the GPHS-RTG provides power in range of 250 to 300 W_e. The proposed advanced RPSs would be physically smaller power systems and would provide lower levels of electric power (approximately 100 W_e) thus enabling NASA to fly smaller missions that require less power than that could be provided by the GPHS-RTG. The advanced RPS units could be utilized in a modular fashion, such that one or more of these devices could be integrated into a spacecraft for a mission requiring higher levels of electric power.

1.4 NEPA PLANNING AND SCOPING ACTIVITIES

On April 24, 2004, NASA published a Notice of Intent (NOI) to prepare an Environmental Impact Statement (EIS) in the *Federal Register* (69 FR 21867) and conduct scoping for the development of advanced RPSs. The scoping period originally was to close on June 4, 2004 but was extended until July 30, 2004 (69 FR 43629). Comments were solicited from Federal, State, and local agencies, and other interested parties on the scope of the EIS. Scoping comments were received from private organizations and individuals. Issues raised in the scoping comments included:

- (1) Concern with the use of radiological material for the spacecraft electrical power source.
- (2) Use of alternative (radiological and non-radiological) sources for electrical power.
- (3) Impacts to workers at the Los Alamos National Laboratory (LANL) due to heat source preparation.
- (4) Impacts to the groundwater at LANL due to plutonium fuel and heat source preparations.
- (5) Concerns about the lack of methods to properly dispose of nuclear waste.
- (6) Concerns about launch-area accidents when using RPSs.
- (7) Possible military applications of the advanced RPS technology.

Issues 1 through 5 are addressed and discussed in this DPEIS. Issues 1 and 2 are summarized in Chapter 2 and discussed more thoroughly in Chapter 4. Comments associated with issues 3, 4 and 5 are not within the scope of this DPEIS since these types of issues are already addressed in existing relevant DOE NEPA documentation that envelopes any impacts that would result from proceeding with the Proposed Action or the No Action Alternative addressed in this DPEIS. Some descriptive information on activities conducted at the various DOE nuclear facility sites is presented in Chapter 4. Comments associated with issue 6 are not within the scope of this DPEIS but concerns associated with launch accidents are discussed qualitatively in Chapter 4 as launches with RPSs could occur. The impacts of such proposed launches would be discussed in detail in mission-specific NEPA documentation. Issue 7 is not within the scope of this DPEIS. DOE is developing the advanced RPSs for NASA's space exploration purposes and not for military purposes.

1.5 NEPA ACTIVITIES RELATED TO THE PROPOSED ACTION

This section provides brief summaries of NEPA documents related to the Proposed Action.

The *Programmatic Environmental Impact Statement for the Mars Exploration Program* (NASA 2005a) evaluates NASA's near and mid-term plans for the Mars Exploration Program, including missions that may require the use of plutonium-238 fueled RPSs and/or Radioisotope Heater Units (RHUs). The record of decision for the Mars Exploration Program was signed on June 20, 2005 completing the NEPA process. The proposed action was selected (NASA 2005b). The first mission to Mars that would consider the use of an advanced RPS is the Mars Science Laboratory mission, currently planned for launch as early as 2009. NASA intends to develop an EIS for this mission in the near future.

The *Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication* (DOE 1991) evaluated the impacts of increased production of plutonium-238 fuel for NASA missions at the Technical Area (TA)-55 facility at LANL. The finding of no significant impact (FONSI) concluded that the RTG and Radioisotope Heater Unit (RHU) component fabrication activities at LANL would not be a major federal action that would significantly affect the quality of the human environment.

The *Environmental Assessment for the Future Location of Heat Source/Radioisotope Power System Assembly and Operations Currently Located at the Mound Site* (DOE 2002b) addressed the options for locating future operations of DOE's plutonium-238 heat source/radioisotope power systems (HS/RPS) fabrication and acceptance test activities. The FONSI concluded that continued operations of the HS/RPS fabrication activities at any of the alternative sites would not be a major federal action that would significantly affect the quality of the human environment. DOE decided to relocate the operations from the Mound Site to the Argonne National Laboratory-West, now part of the Idaho National Laboratory (INL), site in Idaho.

The *Programmatic Environmental Impact Statement for Accomplishing the Isotope Production Missions in the United States, including the Role of the Fast Flux Test Facility* (DOE 2000) (66 FR 7877; 69 FR 50180) evaluated the environmental impacts of alternatives for production of various isotopes, including plutonium-238. The DOE selected the preferred alternative, which included reestablishing domestic production of

plutonium-238. For that purpose, DOE decided that the Advanced Test Reactor (ATR) in Idaho and the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory (ORNL) in Tennessee would be used to irradiate neptunium-237 targets. The Radiochemical Engineering Development Center (REDC) at ORNL would be used for fabricating targets and extracting plutonium-238 from the irradiated targets. In the August 13, 2004 amended Record of Decision (ROD), DOE decided that the neptunium-237 oxide would be shipped from the Savannah River Site to the Argonne National Laboratory-West (ANL-W) (now INL) in Idaho for storage.

The *Environmental Assessment of the Import of Russian Plutonium-238* (DOE 1993a; DOE 1993b) addressed the environmental impacts of importing plutonium-238 from Russia to augment the U.S. inventory for NASA space missions. The proposed action considered shipping up to 40 kilograms (88.2 pounds) of plutonium-238 fuel from Russia to a U.S. port, transporting the plutonium-238 within the U.S. and if necessary, purifying the material to remove various impurities. Based on the analysis in the Environmental Assessment (EA), DOE concluded that the importation of plutonium-238 from Russia would not constitute a major federal action significantly affecting the quality of the human environment.

The *Environmental Assessment of the General-Purpose Heat Source Safety Verification Testing* (DOE 1995) evaluated the impacts of rocket sled testing of GPHS modules using depleted uranium as a simulant for plutonium-238. The FONSI concluded that these tests would not be a major federal action that would significantly affect the quality of the human environment.

The *Site-Wide Environmental Impact Statement for the Continued Operation of the Los Alamos National Laboratory* (DOE 1999a) (64 FR 50797) evaluated ongoing and projected new operations and facilities at LANL in support of DOE missions, including the storage of plutonium-238 and production of fuel clads for U.S. space missions. A decision was made in the ROD to implement the Preferred Alternative, which includes expansion of operations as necessary, increases in existing operations to the greatest reasonably foreseeable levels, and full implementation of the mission elements assigned to LANL.

The *Draft Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to the Production of Radioisotope Power Systems* (DOE 2005a) is being developed by the DOE, with NASA as a cooperating agency, to address impacts associated with the potential consolidation at INL of the activities associated with the production and fabrication of fuel for radioisotope heat sources and RPSs and the assembly and testing of integrated RPS units. The DOE published a draft EIS in June 2005 (70 FR 38132) and the EIS process is scheduled for completion by early 2006. NASA holds no stake in the decision ultimately taken by DOE related to its long-term production of plutonium-238. NASA's Proposed Action in this DPEIS is independent of the Consolidation EIS (DOE 2005a) alternative selected by the DOE.

Launch of space missions with advanced RPSs is beyond the scope of this DPEIS. Launch of the proposed advanced RPSs from any U.S. launch site (*e.g.*, Kennedy Space Center (KSC), Cape Canaveral Air Force Station (CCAFS), Vandenberg Air Force Base (VAFB)) would be subject to mission specific NEPA documentation.

2 DESCRIPTION AND COMPARISON OF ALTERNATIVES

In order to meet the future mission needs for exploration of the solar system, the National Aeronautics and Space Administration (NASA), in cooperation with the U.S. Department of Energy (DOE), proposes to develop two new long-lived, reliable electric power systems. These power systems would be capable of functioning in the environments encountered in space and on the surfaces of planets, moons and other solar system bodies that have an atmosphere (*e.g.*, Mars, Venus, Pluto, and two of the moons of Saturn (Titan and Enceladus)). In the follow-on sections of this chapter, planets, moons, and other solar systems bodies are collectively referred to as solar system bodies.

This Draft Programmatic Environmental Impact Statement (DPEIS) was prepared in accordance with the National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 *et seq.*) and evaluates the following alternatives:

- Proposed Action. The Proposed Action has two basic elements. (1) NASA proposes to develop and qualify for flight and use in space two types of advanced Radioisotope Power Systems (RPS), the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and the Stirling Radioisotope Generator (SRG), to enable a wide range of future space exploration missions. These advanced RPSs would be capable of functioning in the environments encountered in space and on the surfaces of solar system bodies that have an atmosphere. These modular power systems would be based upon an enhanced version of the General Purpose Heat Source (GPHS) fueled by plutonium dioxide (consisting mostly of plutonium-238). The GPHS was originally developed by DOE and used in Radioisotope Thermoelectric Generators (RTGs) on previous NASA missions. (2) The Proposed Action also includes continued research and development (R&D) of alternative radioisotope power systems and power converter technologies.
- No Action. Under the No Action Alternative, NASA would (1) discontinue efforts for the development of the MMRTG and SRG. NASA would continue to consider the use of available RPSs, such as the GPHS-RTG, for future solar system exploration missions. While well suited to use in space, the GPHS-RTG would have substantially limited application on missions to the surface of solar system bodies where an atmosphere is present. In addition, DOE's GPHS-RTG production line is no longer operative, including the Silicon/Germanium (SiGe) thermocouple manufacturing operations. It may be possible to construct a limited number (one or two) of GPHS-RTGs from existing parts inventories, but longer term reliance on this technology would require the reactivation of these production capabilities, including re-establishing vendors for GPHS-RTG components, which could involve a substantial financial investment. In the follow-on sections of this chapter, reactivating the GPHS-RTG production line is inclusive of reactivating the Si/Ge manufacturing operations and re-establishing the supply vendors. (2) As with the Proposed Action, NASA would continue to pursue R&D of alternative radioisotope power systems and power converter technologies.

The long-term NASA R&D efforts involving alternative radioisotope power systems and power converter technologies are on-going activities. This R&D focuses on longer-term improvements to RPSs that are less technologically developed than the MMRTG and SRG, including technologies that increase specific power (electrical power output per unit mass); increase efficiencies for power conversion technologies; improve modularity; increase reliability,

lifetime, and operability; and provide improved capability to operate in harsh environments. These advancements would provide for greater power system flexibility enabling use in more places in space and on solar system bodies. The results of this R&D could be applied to improve the MMRTG or SRG design, and to further evolutionary RPS designs including RPS designs with smaller electrical outputs. Future fabrication of fueled RPSs, qualification units (used to demonstrate the readiness of a design for flight applications) and flight units, stemming from this R&D would be the subject of future environmental documentation. The R&D effort on power conversion technologies have applicability to both radioisotope and non-radioisotope power systems. These NASA R&D activities (see Section 2.3) are addressed under both the Proposed Action and the No Action Alternative as these efforts will continue independent of the decision to be made in this PEIS. In addition, NASA will continue to evaluate power systems developed independently by other organizations for their viability in space-based applications.

2.1 DESCRIPTION OF THE PROPOSED ACTION

Under the Proposed Action, NASA, in cooperation with DOE, would develop the MMRTG and the SRG. These advanced RPS designs would be based on the development of two new power converter systems. Both the MMRTG and the SRG would use enhanced GPHS modules as the heat source. Either could be used to meet many of the electric power needs of potential NASA space exploration missions. Figure 2-1 provides a high-level schedule and milestones for the development of the MMRTG and the SRG.

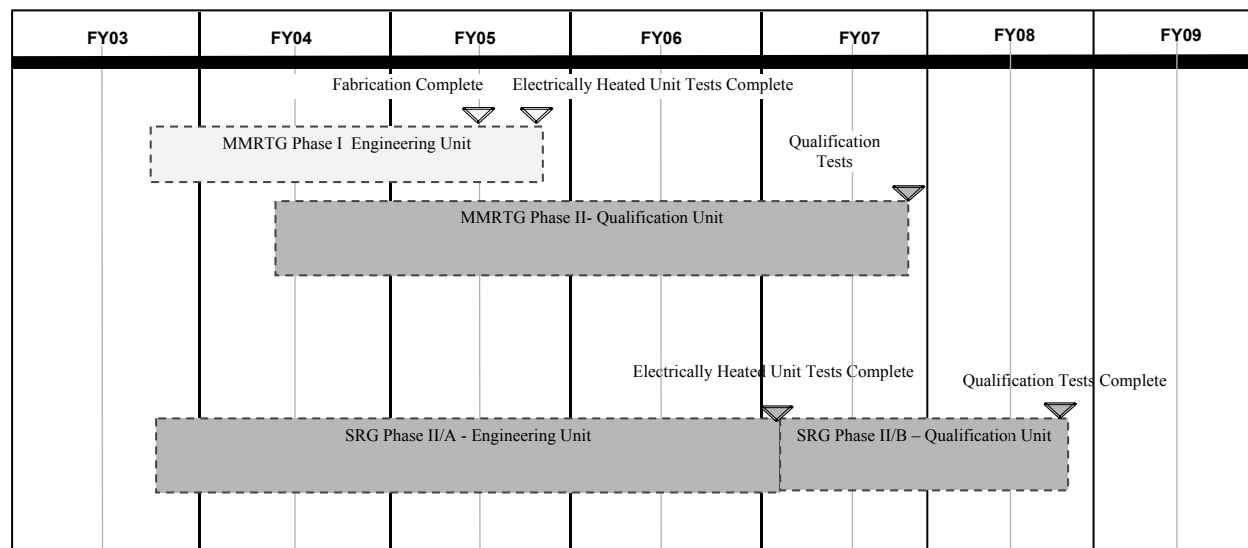


FIGURE 2-1. RPS SCHEDULE AND MILESTONES

The Proposed Action has two basic elements:

1) Final Design, Development, and Testing of the Space-Qualified MMRTG and SRG:

The MMRTG would build upon spaceflight-proven passive thermoelectric power conversion technology while incorporating improvements to allow extended operation on solar system bodies that have an atmosphere. The MMRTG configuration, as proposed, would consist of three basic elements: the heat source, the converter, and an outer case with the heat radiator. The thermoelectric elements that would be employed in the MMRTG have a history of use in diverse environments. The converter thermocouple design is based on the Systems for Nuclear Auxiliary Power (SNAP)-19 RTG, which was used successfully on the Viking Mars Landers and the Pioneer spacecrafts in the 1970's.

For the SRG, NASA, in cooperation with DOE, would develop a new dynamic power conversion system based on the Stirling engine. The Stirling conversion system would convert the heat from the decay of plutonium into electrical power much more efficiently than the MMRTG and therefore use less plutonium to generate comparable amounts of electrical power. Because the SRG uses less plutonium than the MMRTG, the SRG generates less waste (excess) heat – which may be beneficial for some missions where excess heat would adversely impact spacecraft operation or may be undesirable for missions where excess heat from the RPS is needed for warming spacecraft components.

The GPHS-RTG used on NASA's Galileo, Ulysses, Cassini, and the planned New Horizons missions included as a heat source the GPHS modules developed by DOE. The GPHS-RTG, designed to operate un-sealed in space vacuum, used on previous orbital missions has limited applicability on surfaces of solar system bodies where an atmosphere is present. The performance of the converter, specifically the thermocouples and the multi-foil insulation, degrades in planetary atmospheres and does not provide the long-term operating capabilities desired for these surface missions. The advanced RPSs would be capable of providing that long-term, reliable electrical power to spacecraft across the range of conditions encountered in space and on surface missions to solar system bodies that have an atmosphere.

Both of these advanced systems would provide on the order of 100 watts of electric power (W_e) at beginning of mission (BOM) and would be capable of functioning both in the environments encountered in space and on surfaces of solar system bodies that have an atmosphere. The mechanical and thermal interfaces of the MMRTG and SRG respectively, would accommodate a broad range of spacecraft designs. One or more MMRTG or SRG, or a combination of the two, could be integrated with a spacecraft to provide higher power levels, as needed.

2) Future RPS Research and Development: This encompasses R&D of alternative radioisotope power systems and power converter technologies (see Section 2.3 for a detailed discussion).

2.1.1 Facilities Involved

Development and test activities involving the use of radioisotopes would be performed at existing DOE sites and facilities that currently perform similar activities in accordance with DOE's existing NEPA documentation. Fuel production would likely occur at Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico, which is currently used for the

fabrication of the fuel installed in the GPHS modules. (The plutonium dioxide used to fuel RPSs for NASA missions is currently procured by DOE from Russia.) Advanced RPS assembly and qualification and acceptance testing would be performed at Idaho National Laboratory (INL), located west of Idaho Falls, Idaho. These activities were previously performed at DOE's Mound, Ohio facility. (The effort in support of NASA's advanced RPS needs is only a part of DOE's RPS mission. The RPS activities performed by DOE are expected to continue even without any future support for NASA). Any required additional safety testing of an integrated advanced RPS (using low activity-level fuel simulant) could be performed at one or more existing facilities (*e.g.*, LANL, Sandia National Laboratory (SNL) in Albuquerque, New Mexico, or Aberdeen Proving Ground (APG) in Aberdeen, Maryland).

Upon successful completion of advanced RPS development, it is anticipated that these devices would be considered for use on future NASA missions. In those cases additional, mission-specific NEPA analysis would be performed, as required.

Currently, DOE is considering plans to consolidate operations at its INL facility for the domestic production of plutonium; the NEPA process for this action is on-going (DOE 2005a). Three alternatives are being evaluated by DOE for this purpose: the Consolidation Alternative (consolidate all RPS activities at INL); the Consolidation with Bridge Alternative (maintain *status quo* until INL facilities become operative); and the No Action Alternative (maintain *status quo*). NASA holds no stake in the decision ultimately taken by DOE related to its long-term production of plutonium-238. NASA's Proposed Action in this DPEIS is independent of the Consolidation EIS (DOE 2005a) alternative selected by the DOE.

2.1.2 RPS Overview

2.1.2.1 Background

Radioisotope Power Systems (RPSs) generate electrical power by converting the heat released from the nuclear decay of radioisotopes, such as plutonium-238, into electricity. First used in space by the United States of America (U.S.) in 1961, these devices have consistently demonstrated unique capabilities over other types of space power systems for applications up to several hundred watts of electric power. Radioisotopes also serve as a versatile energy source for heating and maintaining the temperature of sensitive electronics in space. A key advantage of using RPSs is their ability to operate continuously; both further away from and closer to the Sun than other existing space power technologies. RPSs are long-lived, rugged, compact, highly reliable, and relatively insensitive to radiation and other environmental effects. As such, they enable missions involving long-lived, autonomous operations in the extreme conditions of space and the surfaces of solar system bodies. The GPHS-RTG, used on the ongoing Cassini mission to Saturn and the planned 2006 New Horizons mission to Pluto is an RPS that is capable of operating in the vacuum of space; however, it has limited capabilities for operating on landed missions where an atmosphere is present. With the appropriate design, such as on the SNAP-19 RTG for the Viking missions, an RPS would have the capability to function in a wider range of landed conditions than the GPHS-RTG.

Table 2-1 lists all of the 24 U.S. space missions that have used RPSs. Many of these, particularly the ones used on the Apollo lunar missions, the Viking Mars landers, and the Pioneer and Voyager planetary probes, produced electrical power well beyond their required lifetimes. The RPSs on the three aborted missions met their respective design criteria. The RPS on the first

TABLE 2-1. U.S. MISSIONS USING RADIOISOTOPE POWER AND HEAT SOURCES

	Spacecraft	Principal Energy Source (# of units)	Destination/ Application	Launch Year	Status
1	Transit 4A	SNAP-3B7 RTG (1)	Earth Orbit/ Navigation Satellite	1961	RTG operated for 15 years. Satellite now shutdown.
2	Transit 4B	SNAP-3B8 RTG (1)	Earth Orbit/ Navigation Satellite	1961	RTG operated for 9 years. Operation intermittent after 1962 high altitude test. Last signal in 1971.
3	Transit 5BN-1	SNAP-9A RTG (1)	Earth Orbit/ Navigation Satellite	1963	RTG operated as planned. Non-RTG electrical problems on satellite caused failure after 9 months.
4	Transit 5BN-2	SNAP-9A RTG (1)	Earth Orbit/ Navigation Satellite	1963	RTG operated for over 6 years. Satellite lost navigational capability after 1.5 years.
5	Transit 5BN-3 [a]	SNAP-9A RTG (1)	Earth Orbit/ Navigation Satellite	1964	Mission aborted because of launch vehicle failure. RTG burned up on reentry as designed.
6	Nimbus B-1 [b]	SNAP-19B2 RTG (2)	Earth Orbit/ Meteorology Satellite	1968	Mission aborted because of range safety destruct. RTG heat sources recovered and recycled.
7	Nimbus III	SNAP-19B3 RTG (2)	Earth Orbit/ Meteorology Satellite	1969	RTGs operated for over 2.5 years. No data taken after that.
8	Apollo 11	ALRH Heater	Lunar Surface/ Science Payload	1969	Heater units for seismic experimental package. Station shut down August 3, 1969.
9	Apollo 12	SNAP-27 RTG (1)	Lunar Surface/ Science Station	1969	RTG operated for about 8 years until station was shutdown.
10	Apollo 13 [c]	SNAP-27 RTG (1)	Lunar Surface/ Science Station	1970	Mission aborted. RTG reentered intact with no release of Pu-238. RTG currently located at bottom of Tonga Trench in South Pacific Ocean.
11	Apollo 14	SNAP-27 RTG (1)	Lunar Surface/ Science Station	1971	RTG operated for over 6.5 years until station was shutdown.
12	Apollo 15	SNAP-27 RTG (1)	Lunar Surface/ Science Station	1971	RTG operated for over 6 years until station was shutdown.
13	Pioneer 10	SNAP-19 RTG (4)	Planetary/Payload & Spacecraft	1972	RTGs still operating. Spacecraft now well beyond orbit of Pluto.
14	Apollo 16	SNAP-27 RTG (1)	Lunar Surface/ Science Station	1972	RTG operated for about 5.5 years until station was shutdown.
15	Triad-01-1X	Transit-RTG (1)	Earth Orbit/ Navigation Sat	1972	RTG still operating as of mid-1990s.
16	Apollo 17	SNAP-27 RTG (1)	Lunar Surface/ Science Station	1972	RTG operated for almost 5 years until station was shutdown.
17	Pioneer 11	SNAP-19 RTG (4)	Planetary/Payload & Spacecraft	1973	RTGs still operating. Spacecraft operated to Jupiter, Saturn and beyond.

**TABLE 2-1. U.S. MISSIONS USING RADIOISOTOPE POWER AND HEAT SOURCES
(CONTINUED)**

	Spacecraft	Principal Energy Source (# of units)	Destination/ Application	Launch Year	Status
18	Viking 1	SNAP-19 RTG (2)	Mars Surface/Payload & Spacecraft	1975	RTGs operated for over 6 years until lander was shutdown.
19	Viking 2	SNAP-19 RTG (2)	Mars Surface/Payload & Spacecraft	1975	RTGs operated for over 4 years until relay link was lost.
20	LES 8, LES 9 [d]	MHW-RTG (4)	Earth Orbit/ Communication Satellites	1976	RTGs were still operating as of mid-1990s.
21	Voyager 2	MHW-RTG (3)	Planetary/ Payload & Spacecraft	1977	RTGs still operating. Spacecraft successfully operated to Jupiter, Saturn, Uranus, Neptune, and beyond.
22	Voyager 1	MHW-RTG (3)	Planetary/ Payload & Spacecraft	1977	RTGs still operating. Spacecraft successfully operated to Jupiter, Saturn, and beyond.
23	Galileo	GPHS-RTG (2) RHU Heater (120)	Planetary/Payload & Spacecraft	1989	RTGs continued to operate until 2003, when spacecraft was intentionally deorbited into Jupiter atmosphere.
24	Ulysses	GPHS-RTG (1)	Planetary/Payload & Spacecraft	1990	RTG continues to operate successfully after 14 years. Spacecraft conducting polar solar orbits.
25	Mars Pathfinder	RHU Heater (3)	Mars Surface/Rover Electronics	1996	Heater units used to maintain payload temperature. Units still presumed active.
26	Cassini	GPHS-RTG (3) RHU Heater (117)	Planetary/Payload & Spacecraft	1997	RTGs continue to operate successfully after 8 years. Spacecraft in Saturn orbit.
27	Mars MER Spirit	RHU Heater (8)	Mars Surface/Rover Electronics	2003	Heater units are operational and used to maintain payload temperature.
28	Mars MER Opportunity	RHU Heater (8)	Mars Surface/Rover Electronics	2003	Heater units are operational and used to maintain payload temperature.
29	Pluto New Horizons	GPHS-RTG (1)	Planetary/Payload & Spacecraft	2006	Planned for launch in Jan 2006.

Source: Derived from NASA 2005c

- a. Mission was aborted due to launch vehicle failure. RTG burned up on reentry as designed.
- b. Mission was aborted due to launch vehicle failure. RTG heat sources recovered, plutonium recycled and used on subsequent mission.
- c. Mission aborted on way to Moon. RTG reentered Earth atmosphere intact with no release of Pu-238. It is currently located deep in the Tonga Trench in the South Pacific Ocean.
- d. Mission consisted of two RPS-powered communications satellites (LES 8 and 9) launched on a single booster.

aborted mission burned up on orbital reentry, a design goal that has since been superseded by a design requirement for intact reentry from orbit. The heat sources from the second aborted mission survived reentry and impact with no plutonium release and were recovered. The plutonium was then used on a subsequent mission. The RPS from the Apollo 13 mission reentered intact with no known plutonium releases and currently lies at the bottom of the Tonga Trench in the South Pacific Ocean (DOE 1980).

Radioisotope Power Systems consist of two principal subsystems: a heat source and a power converter. The heat source includes the radioisotope fuel encapsulated within a protective clad designed to contain the fuel and limit the possibility of its dispersal to the maximum extent practical during launch accidents, such as inadvertent atmospheric reentry and impact. The heat produced from this thermal source flows via radiative and conductive transfer to a power converter, which transforms a portion of the heat into electricity. The remaining unconverted heat may be used for purposes other than electric power generation or is ultimately rejected to the surrounding environment via radiators.

All RPS units flown by NASA have used plutonium dioxide as the fuel. The radioactive decay of plutonium (via alpha particle emissions) generates approximately $0.57 W_{th}$ per gram (g) (0.035 ounces (oz)) of plutonium-238. In the GPHS (Figure 2-2) the plutonium dioxide (in the form of a ceramic pellet) is encased in a protective clad to prevent release into the environment and a series of protective shells designed to prevent damage to the clad during launch accidents, inadvertent reentry, and impact. These protective features are an integral part of the GPHS design. Each GPHS module contains four fueled clads of plutonium dioxide with a total mass of approximately 600 g (21 oz) and produces roughly $250 W_{th}$ at BOM. The GPHS is designed as an independent module to enhance safety in the event of inadvertent reentry by an RPS, and to allow its use as a building block in future RPS configurations with different thermal outputs and power levels.

An enhanced GPHS module design would be used in the MMRTG and SRG designs. This enhanced GPHS module would provide added factors of safety in both module impact conditions and in inadvertent reentry scenarios. The conceptual design of the enhanced GPHS includes the addition of 0.25 centimeters (cm) (0.1 inch (in)) of graphite material in the center of the module between the graphite impact shells and an increase of 0.25 cm (0.1 in) in the thickness of the two module broad faces. Table 2-2 presents the anticipated mass specifications for the enhanced GPHS.

All RPS units flown by the U.S. have used thermoelectric devices to convert decay heat into electricity. They have all operated at power levels ranging from several watts to several hundred watts. The SNAP-19 RTG, whose thermocouple design would be adapted for the MMRTG, was designed to provide approximately $40 W_e$ at launch. The GPHS-RTG has been used in NASA's most recent RPS-powered missions. It has a length, diameter, and mass of 114 cm (44.9 in), 42 cm (17 in) and 57 kilograms (kg) (124 pounds (lb)), respectively. It is designed to generate approximately $285 W_e$ at launch from a stack of 18 GPHS modules. Because the heat is generated by radioactive decay of plutonium-238, the amount of plutonium in the RPS and subsequently the power produced decreases over the lifetime of the mission. Individual thermocouples use dissimilar, electrically-conductive materials to produce electricity directly from the temperature difference between the hot and cold sides of a closed circuit. This GPHS-

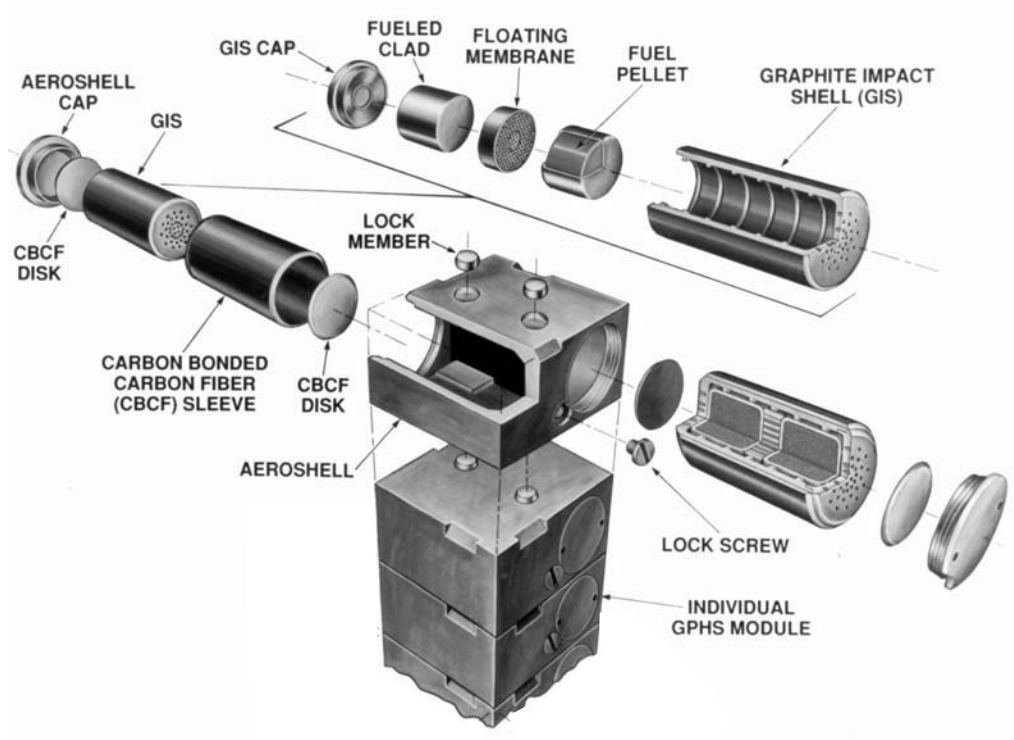


FIGURE 2-2. GPHS MODULE

TABLE 2-2. ENHANCED GPHS MASS BREAKDOWN (ANTICIPATED)

Component	Material	Mass (grams)	Mass (ounces)
Fuel Pellets (4)	Plutonium dioxide	600	21
Clads (4)	Iridium	230	8.0
Impact Shells (2)	FWPF – 3D Graphite	180	6.4
Floating Members (2)	FWPF – 3D Graphite	6.8	0.24
Insulator	CBCF - Graphite	8.6	0.30
Aeroshell (includes caps (2) & lock screws (2))	FWPF* – 3D Graphite	580	20
Total		1600	56

Source: NASA 2004b

*FWPF-Fine Weave Pierced Fabric; CBCF-Carbon Bonded Carbon Fiber

RTG converts about 6 to 7% of the heat generated into electrical power and the remainder is dissipated through its aluminum housing and radiator fins.

2.1.2.2 MMRTG and SRG Development

The MMRTG and SRG are planned to be available starting in 2009 and 2010 respectively. As shown in Table 2-3, both units are being developed to meet similar top-level requirements in terms of power, lifetime, and operating environments. They differ in their methods of converting thermal energy to electric power, and the number of enhanced GPHS modules used to generate heat.

The difference in power conversion technologies is the principal reason for developing two systems with similar capability. The MMRTG (Figure 2-3) is based on the thermoelectric conversion technology used on the SNAP-19 RTG for Viking and Pioneer missions, and represents a low development-risk option. However, as a state-of-practice RPS, the MMRTG does not improve upon the thermal-to-electric power conversion efficiency of the GPHS-RTG. The MMRTG approach entails low development risk, but requires fabricating a relatively large number of heat sources, which would place greater demands on cost and schedule and production capabilities at DOE facilities compared to more efficient converter technologies.

The SRG (Figure 2-4) is four times more efficient than the MMRTG, and thus would require one-fourth as much plutonium-238 for a similar power level. This would ease demand on the plutonium dioxide supply and production infrastructure. However, this technology has not been demonstrated in space for this specific application - the generation of electricity from heat - and represents a higher development risk.

Table 2-4 provides a list of significant attributes of the MMRTG and SRG, highlighting the differing (and complimentary) capabilities and limitations of each design. These attributes are expected to affect future NASA decisions on the use of MMRTG or SRG systems for particular missions.

NASA R&D activities progress through phases from initial basic scientific research to the ability to deploy (launch and operate) a fully operational system design. This effort can be broadly described as follows:

- Basic Technology Research - identifying basic scientific principles and formulating technology concepts or applications;
- Research to Prove Feasibility - analytical and experimental efforts to show proof-of-concept;
- Technology Development - validation of component operability in a representative environment;
- Technology Demonstration - system or prototype demonstration in a representative environment;
- System Development: through first unit fabrication - system qualified through test and demonstration either in ground test or flight tests; and
- System Launch and Operations - successful first system operation on a mission.

This DPEIS addresses the MMRTG and SRG through System Development, *i.e.*, through fabrication and test of the first unit, which for both advanced RPS designs is a Qualification Unit

TABLE 2-3. TOP-LEVEL REQUIREMENTS FOR MMRTG AND SRG

Requirement	MMRTG	SRG
Heat Source Quantity	8 GPHS Modules (~4.8 kg Pu-238)	2 GPHS Modules (~1.2 kg Pu-238)
Beginning of Mission Thermal Inventory	250 +/- 6 W _{th} per GPHS module	
Delivered Electrical Power	≥110 W _e at Beginning of Mission	
Environment	Operate in deep space and on surface of Mars. Mars surface is characterized as 6-10 torr CO ₂ atmosphere with daily temperatures ranging from 170-270 Kelvin with varying amounts of suspended and deposited dust.	
Lifetime	Provide power for ≥14 years.	
Voltage	Operate over a range of 23 – 36 volts (direct current) and provide maximum power over the life of the mission with a spacecraft bus operating at 28 +/- 0.2 volts (direct current).	
Reliability	Maximize reliability. Avoid single point failures.	
Mass	As small and lightweight as possible while maximizing specific power (W _e /kg).	
Power during launch	Maximize power (power output should be at least 80% of full power) during launch.	
Size	Fit within maximum acceptable envelope for DOE shipping container (USA/9904/B(U)-F-84) used to transport fueled systems.	
Operations	Allow use on missions involving multiple Venus gravity assist maneuvers.	
Design Vibration Load*	0.2 g ² /Hz	
Design Acceleration Load*	40 g	30 g (assessing to 40 g)
EMI/EMC	Designed to EMI/EMC Standard 461C and meet magnetic requirements of 25 nT at 1-meter.	
Sterilization (Mars only)	NASA Designated.	
Mission-specific Heat Rejection	Allow complete waste heat removal by cooling loops or by radiation heat transfer to space or any combination of both methods.	
Radiation Environment	Withstand radiation environments encountered on surface of Mars	
Safety	Minimize impact to safety that components may have on integrity of GPHS modules and fuel clads during an accident. The generator design in and of itself shall not impede the free and clear release of GPHS modules under a reasonable range of inadvertent Earth reentry conditions established jointly by NASA and DOE. Use of passive design features to facilitate free and clear release of GPHS modules shall be considered.	

Source: NASA 2004b

* g = gravitational acceleration

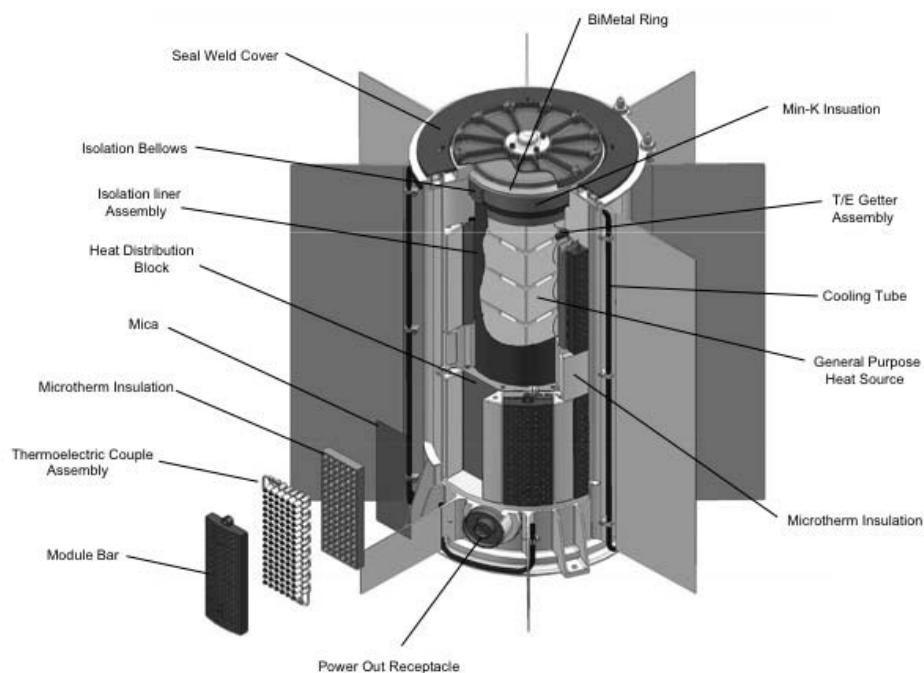


FIGURE 2-3. MULTI-MISSION RADIOISOTOPE THERMOELECTRIC GENERATOR

used in ground testing. The R&D involved in power converter technology extends only up to the Technology Development or Technology Demonstration phases.

2.1.3 Research, Development and Fabrication of the MMRTG

2.1.3.1 MMRTG Background

The MMRTG design improves upon the technology heritage of previous RTGs (particularly the SNAP-19 RTG and GPHS-RTG) to expand the mission environments in which RPSs could be used. The SNAP-19 RTG powered the Viking Mars landers and Pioneer interplanetary probes, while the GPHS-RTG was used on the Galileo, Ulysses, and Cassini orbital missions. The MMRTG would use eight plutonium-fueled enhanced GPHS modules as heat sources. Included with the heat source would be a device for collecting and venting the helium gas generated from plutonium fuel decay. The power conversion system would consist of a lead-telluride (PbTe) negative terminal and a segmented positive terminal consisting of a lead-tin-telluride (PbSnTe) hot segment and tellurides of antimony-germanium-silver (TAGS) thermocouples capable of converting the decay heat of the plutonium directly into electricity. These thermoelectric materials are contained within a sealed converter with an Argon cover gas. Such converter designs have demonstrated extended lifetime and performance capabilities and have a history of use in diverse environments ranging from the oxidizing atmosphere of Mars to the vacuum environment of space. In fact, much of the thermocouple design for the MMRTG is based on the SNAP-19 RTG thermocouples. Design improvements would give the MMRTG the capability to operate on solar system bodies with an atmosphere as well as in space for extended periods of time. The MMRTG would be designed to generate at least 110 W_e at launch, with a converter

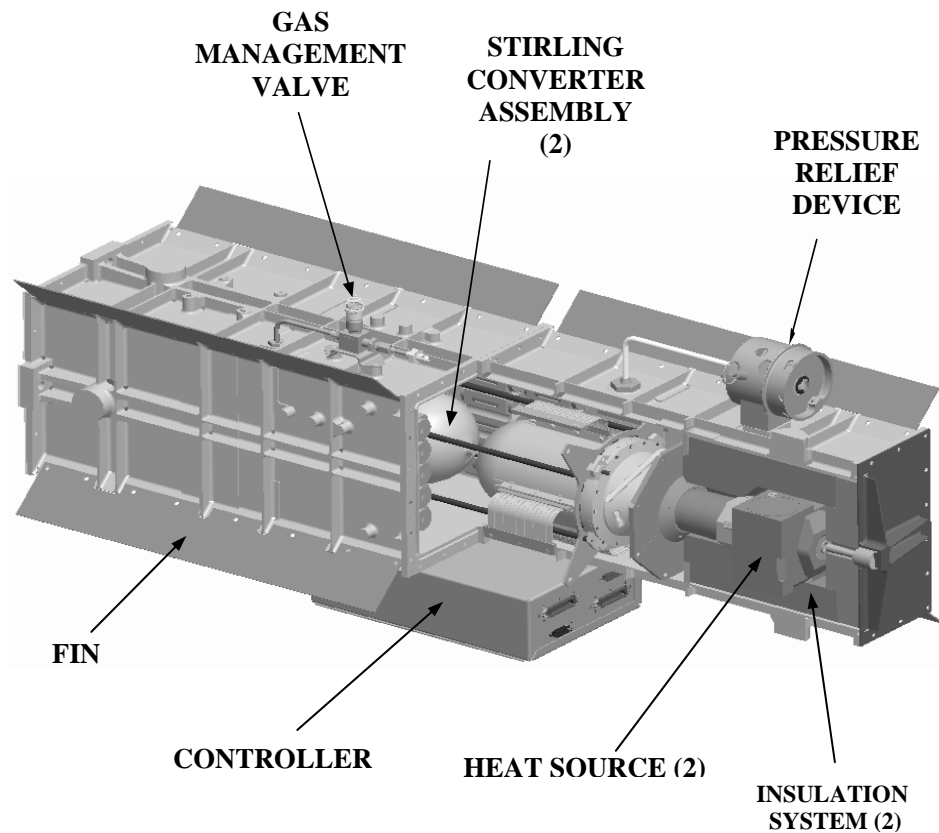


FIGURE 2-4. STIRLING RADIOISOTOPE GENERATOR

efficiency of about 6%. The MMRTG would provide a more flexible modular design (compared to the 285 W_e GPHS-RTG) and would be better suited to meet the needs of a wider variety of missions. The design goals for the MMRTG would include ensuring a high degree of safety; optimizing power levels over a minimum lifetime of 14 years, and minimizing weight (see Table 2-3).

Waste heat from the MMRTG would be dissipated from the converter housing via eight conductive fins positioned radially around the housing. These fins define an MMRTG volumetric envelope approximately 66 cm (26 in) in length and 64 cm (25 in) in diameter (*i.e.*, distance between tips of opposing fins). The mass of each MMRTG unit would be approximately 42 kg (93 lb). The housing and fins would be coated with a high emissivity material to promote heat transfer to the environment. An auxiliary cooling loop running along the base of each fin could be mated with an external heat removal system for missions or mission phases requiring active cooling.

TABLE 2-4. COMPARISON OF ATTRIBUTES BETWEEN THE MMRTG AND THE SRG

Attribute	MMRTG	SRG
Lifetime	Expected to provide long-life power supply	
Power Level	Modular power in approximately 110 W _e increments	
Fuel Mass	Uses 8 GPHS modules containing a total of 4.8 kg (10.5 lb) of plutonium dioxide	Uses 2 GPHS modules containing a total of 1.2 kg (2.6 lb) of plutonium dioxide
Conversion Mechanism	Passive system, no moving parts	Dynamic system with moving parts
Technological Readiness	Anticipated to be qualified for flight by 2007	Anticipated to be qualified for flight by 2009
Flight Heritage	Derived from previously flown configurations	Power conversion technology has been used for terrestrial applications only, Stirling cryocoolers (with similar dynamic components) have a space flight heritage
Environmental Compatibility	Able to operate in the vacuum of space and on solar system bodies with an atmosphere	
Thermal Characteristics	Fuel initially provides approximately 2000 W _{th} . More excess heat than the SRG. Potential benefit is mission specific (<i>e.g.</i> heat available if needed to keep electronics warm).	Fuel initially provides approximately 500 W _{th} . Less waste heat than the MMRTG. Potential benefit is mission specific (<i>e.g.</i> reduced need for auxiliary heat rejection system).
System Mass	The MMRTG is expected to be approximately 10 to 25% heavier than the SRG. Mass of associated support or interface equipment on spacecraft (<i>e.g.</i> auxiliary heat rejection system, electronics, shielding, etc) and level of system redundancy will be mission specific.	
Radiation Tolerance	High inherent radiation tolerance	Power electronic components may need to be radiation hardened or shielded for high radiation environments
Vibration	No vibration.	Low level vibration may transmit to the mission platform. May need mitigation to prevent adverse impacts on some science instruments. Some vibration may not be mitigable.
Electromagnetic Compatibility	Delivers DC power. Creates a DC magnetic field.	Delivers DC power with an AC component. Creates an AC magnetic field which may need to be shielded when used with AC field-sensitive spacecraft instruments.
Radiation Field	Differing quantities and placement of fuel between MMRTG and SRG may impose differing worker radiation protection requirements during assembly and spacecraft integration, and differing shielding requirements for radiation-sensitive spacecraft instruments.	

2.1.3.2 MMRTG Development

In 2003, DOE, in cooperation with NASA, awarded a contract to Boeing's Rocketdyne (now Pratt & Whitney Rocketdyne) division with Teledyne Energy Systems as a major subcontractor to design, develop, qualify, and produce MMRTGs for consideration for use on future NASA space exploration missions. The intent of this effort would be to develop the MMRTG as an

option for potential use on the Mars Science Laboratory, which is planned for launch as early as 2009. The MMRTG could also serve as an option for other NASA space science missions that would be launched in 2009 or later. Such use of the MMRTG could require it to operate in environments more diverse than those encountered previously by the GPHS-RTGs. As described earlier, the MMRTG would include the enhanced GPHS module, which incorporates design features intended to reduce the size of a release in the event of an inadvertent reentry and impact. The MMRTG design would also incorporate those design features.

Much of the MMRTG design, integration, and testing with electrical heaters simulating the GPHS modules (*i.e.*, Engineering Unit testing) would occur at the Pratt & Whitney Rocketdyne facilities in Canoga Park, California and the Teledyne Energy Systems facilities in Hunt Valley, Maryland. Integrating the MMRTG converter with the enhanced GPHS (*i.e.*, fueling the MMRTG with plutonium dioxide) produces a Qualification Unit. Testing of the Qualification Unit would occur at the DOE fueling and test facility at INL.

The activities associated with the development of the Engineering Unit (which will not be radioisotope fueled) are underway. These ongoing activities associated with MMRTG R&D have been evaluated and were determined to qualify for a Categorical Exclusion under NASA NEPA regulations at 14 CFR 1216.305 (d) (NASA 2003).

Figure 2-1 illustrates the proposed overall schedule for the MMRTG development efforts.

2.1.3.3 Technology Transition to Flight for MMRTG

In addition to the testing performed by DOE and its contractors, NASA is performing tests required to establish the technology transition to flight for potential space missions for the MMRTG. The MMRTG test activities are to be conducted mainly at JPL, but may occur at other NASA sites as well.

Included in Table 2-5 are some of the future tests planned for the transition to flight effort. Additional tests beyond those currently planned may be required as part of this effort. All future planned activities are expected to be performed at existing facilities, although specific test apparatus may need to be fabricated. All current and future test activities would use electrically-heated converters when a heat source would be required. No radioisotope fuel would be used for these tests.

2.1.4 **Research, Development and Fabrication of the SRG**

2.1.4.1 SRG Background

The SRG is the second of the advanced RPS technologies proposed for development to provide spacecraft electric power for potential use on future NASA missions. The SRG would build upon a 55 W_e Stirling converter developed previously under DOE contract. Efficiency of the Stirling converter has been demonstrated to be in the mid-20% range. Use of two 55 W_e Stirling converters in an SRG would provide a total output of about 110 W_e.

The Stirling converter is a free-piston machine that operates on the Stirling thermodynamic cycle. Heat is supplied to the converter from an enhanced GPHS module containing approximately 600 g (21 oz) of plutonium dioxide producing about 250 W_{th}. The closed-cycle system converts heat from an enhanced GPHS module into motion of a reciprocating piston,

TABLE 2-5. PLANNED MMRTG AND SRG TEST ACTIVITIES

Test	Key Feature
Durability	Continuous operations test of flight prototypes
Thermal Vacuum	Approximate temperature and pressure conditions associated with operation in space
Heater head ¹ life assessment	Creep tests to evaluation the change in Stirling engine heater head dimensions due to long exposure to operating temperatures
Aging	Evaluation of changes in thermoelectric properties with time
Life testing	MMRTG thermocouple life testing
Magnet Aging	Evaluate the magnets in the SRG linear alternator for long-term aging characterization, magnet strength, and demagnetization resistance.
Organic	Long term durability testing of the organic material in the SRG linear alternator
Material Properties	Sublimation testing of thermoelectric materials
Launch Environment	Structural response to the stresses associated with launch

Source: GRC 2004c, NASA 2005d

¹The heater head is the thin walled pressure vessel that maintains the temperature differential of the thermodynamic cycle.

which drives a linear alternator that produces an alternating current (AC), which a direct current (DC) converter converts to DC power.

Each 110 W_e SRG would require two enhanced GPHS modules, compared to the eight GPHS modules for the 110 W_e MMRTG and 18 GPHS modules for the GPHS-RTG (which generates approximately 285 W_e). The SRG is expected to be approximately 104 cm (41 in) in length and 29 cm (11 in) by 38 cm (15 in) width and height. The mass of each 110 W_e SRG unit would be approximately 34 kg (75 lb).

2.1.4.2 SRG Development

A technology assessment performed by DOE in 1999 determined that the Stirling power conversion technology had matured sufficiently to initiate development of a flight-qualified SRG (NASA 2004a). In 2002, DOE, with funding from NASA, awarded a contract to Lockheed Martin Space Sciences Company with Stirling Technology Company (now Infinia Corporation) as a major subcontractor to design, develop, qualify, and produce SRGs for consideration for use on future NASA space exploration missions. The GRC is also a team member providing technical support to transition the technology to flight qualification.

It is expected that some SRG design, integration, and testing of the electrically-heated Engineering Units would occur at the Infinia Corporation facilities in Kennewick, Washington and the Lockheed Martin facilities in King of Prussia and Newtown, Pennsylvania. Fueling with plutonium dioxide and testing of the Qualification Unit would occur at the DOE fueling and test facility at INL.

The activities associated with the development of the Engineering Unit, which will not be radioisotope fueled, are underway. These ongoing activities associated with SRG R&D have

been evaluated and were determined to qualify for a Categorical Exclusion (NASA 2003) under NASA NEPA regulations at 14 CFR 1216.305 (d).

Figure 2-1 illustrates the proposed overall schedule for the SRG development efforts.

2.1.4.3 Technology Transition to Flight for SRG

In addition to the testing performed by DOE and its contractors, NASA is performing tests required to establish the technology transition to flight for potential space missions for the SRG. The SRG test activities are to be conducted mainly at GRC, but may occur at other NASA sites as well.

Included in Table 2-5 are some of the future tests planned for the transition to flight effort. Additional tests beyond those currently planned may be required as part of this effort. All future planned activities are expected to be performed at existing facilities, although test specific test apparatus may need to be fabricated. All current and future test activities at would use electrically-heated converters when a heat source would be required. No radioisotope fuel would be used for these tests.

2.1.5 Plutonium-238 Importation and Transportation to LANL

Under the Proposed Action, plutonium-238 would be needed for the Qualification Units for both the MMRTG and the SRG. Over the near term, DOE would continue exercising its option to purchase Russian plutonium-238 (if available) to meet the needs of potential NASA missions. Fuel for the first advanced RPS units would likely come from this source.

Over the longer term, DOE intends to reestablish its ability to produce plutonium-238 domestically. The environmental impacts of this option have been evaluated and reported in the *Programmatic Environmental Impact Statement for Accomplishing the Isotope Production Missions in the United States, including the Role of the Fast Flux Test Facility* (DOE/EIS-0310, December 2000; Records of Decision January 26, 2001 [66 *Federal Register* (FR) 7877] and August 13, 2004 [69 FR 50180]) (DOE 2000).

In 1992, DOE signed a five-year contract for the purchase from Russia of up to 40 kg (88 lb) of plutonium-238, which was extended by another five years in 1997 (DOE 1997). In February of 2003, DOE agreed to purchase up to 60 million dollars worth of plutonium-238, about 30 kg (66 lb), from Russia over a five-year period beginning in 2004. DOE anticipates continued interim purchases of plutonium-238 from Russia pending completion of DOE's proposed consolidation of nuclear operations related to production of RPSs (Wahlquist 2002). The DOE published a notice of availability of a Draft EIS (Consolidation EIS-DOE 2005a) for this purpose in June 2005 (70 FR 38132).

Plutonium-238 purchased from Russia would have to be transported from Russia to a U.S. port of entry, and thereafter to LANL, where it would be used in the fabrication of radioisotope power systems and heating units. Transportation of the plutonium-238 within the U.S. would be by truck, using the DOE's Secure Transportation System (STS) (DOE 1993a).

2.1.6 Plutonium Dioxide Fueled Clad Production at LANL

Fuel fabrication would likely occur at existing facilities at LANL, which are currently used for fabrication of the fuel for the GPHS modules. All fuel fabrication activities occur in Technical Area (TA)-55-4, the Plutonium Handling Facility, Building 4.

The plutonium is received at LANL in the form of plutonium dioxide powder. Upon receipt, the powder is temporarily stored in one of the plutonium process facility vaults. After removal from the vault, all fabrication operations are performed in glove boxes (airtight enclosures with independent ventilation that separate workers from equipment used to handle hazardous material while allowing the worker to use the equipment). The powder is cold compressed and granulated in preparation for sintering (heating to a high temperature, below the material's melting point) at over 2,700 degrees Fahrenheit ($^{\circ}$ F) (1,500 degrees Celsius ($^{\circ}$ C)) and hot pressing into a ceramic pellet form (DOE 1991).

The plutonium dioxide fuel pellet is encased in a welded iridium alloy clad. This process is performed in a glove box with a helium atmosphere. After surface decontamination, the clad pellets are tested to ensure that all design specifications are met (DOE 1991). Under the Proposed Action, LANL would process enough plutonium dioxide fuel (less than 10 kg (22 lb)) for two Qualification Units, one each for the MMRTG and the SRG.

2.1.7 Advanced RPS Operations at INL

Fueling of the MMRTG and SRG Qualification Units, integration of the fabricated fueled clads with the enhanced GPHS modules and integration of the modules with the MMRTG and SRG converters, would occur at INL. The integration and fueling activities would be conducted at currently existing and operating facilities. After integration and fueling, acceptance and qualification testing would be performed in currently operating facilities.

Each generator would undergo a series of acceptance tests. These tests would be expected to be similar to those performed for past missions such as the Cassini mission (DOE 2002b; Lockheed Martin 1998; Lockheed Martin 1997). Following fabrication, each generator would be processed and tested with an electric heat source in the loading and assembly station. The generator would then be shipped to an INL RPS assembly facility for fueling by insertion of the GPHS modules into the generator.

The RPS fueling operation would be performed in the Space and Security Power Systems Facility at INL. After fueling, the Qualification Unit would undergo a series of tests to confirm that the design meets flight requirements. The actual tests required would vary depending on the system requirements. Typically, these tests have been designed to verify the performance of the systems under a variety of conditions, including vacuum to simulate a space environment and significant vibration levels similar to those that would be encountered during launch. Basic system parameters are also measured, including mass properties, magnetic properties, and electrical performance.

2.1.8 Advanced RPS Safety Testing

The data obtained over a 30-year test program by the DOE provide a detailed database to support computer modeling of the behavior of the GPHS module under severe accident conditions. Test data are used to calibrate three-dimensional, numerical models that predict the behavior of the

GPHS modules and the distortion of the fueled clads. DOE would use these techniques to support detailed evaluation of the effects of launch accidents on the GPHS. Safety analyses prepared during the development of the advanced RPSs would be based on such test data and modeling. Additional safety testing of the MMRTG and SRG configurations may be necessary to support the safety analyses. However, such testing is not planned at this time, as it is not known if such testing would be necessary to support the DOE safety analyses.

2.1.9 End Use of Advanced RPSs

This DPEIS addresses the development and fabrication of two advanced RPS designs, but does not encompass the use of an advanced RPS on a mission, nor transportation of the advanced RPS to the launch site. Launch and flight activities would be the subject of future NEPA documentation. However, Section 4.1.7 qualitatively addresses the potential impacts of use of an advanced RPS. A brief description of the end use activities is provided here.

An advanced RPS, after passing acceptance testing, would be shipped to the launch site (*e.g.*, Kennedy Space Center) and temporarily stored. The advanced RPS would be integrated with the spacecraft, typically a few days prior to launch. Missions that would consider the use of an advanced RPS would typically be solar system exploration missions. After launch, the spacecraft, with the advanced RPS, would be placed into a trajectory consistent with the mission design and would not be expected to return to Earth.

2.2 DESCRIPTION OF THE NO ACTION ALTERNATIVE

The only alternative to the Proposed Action that is evaluated is the No Action Alternative in which NASA would forego development of the MMRTG and the SRG. Under the No Action Alternative, NASA would continue to consider for use the current space-proven DOE systems; the RHU, which supplies about 1 W_{th}; and the GPHS-RTG that provides roughly 285 W_e in a space environment only, not for extended periods on the surfaces of solar system bodies that have an atmosphere. However, DOE's GPHS-RTG production line is no longer operative and would require reactivation, which may necessitate additional environmental evaluations.

In addition to considering systems that use the GPHS-RTG, NASA will continue to pursue the R&D of radioisotope power systems and power converter technologies (see Section 2.3 for a detailed discussion).

Selection of the No Action Alternative potentially affects the science return of future NASA missions by eliminating from consideration for use potential power sources that have greater operational capabilities (*i.e.*, operate on solar system bodies that have an atmosphere, improved modularity). The launch frequency and potential environmental impacts could be similar to or less than those in the Proposed Action. As with the Proposed Action, launch and flight activities under the No Action Alternative would be the subject of future NEPA documentation. (The potential impacts associated with the end use of the GPHS-RTG, and the MMRTG and SRG if the Proposed Action is implemented, would depend upon the number of missions that ultimately select an RPS as a power supply. Historically, NASA has launched a mission using an RPS only once every several years. The frequency of future RPS-powered missions would be influenced by several factors, including; future NASA mission priorities, budgetary considerations, and the types of science and exploration missions that could be enabled by an RPS. As indicated above, under the No Action Alternative fewer types of missions are enabled by the GPHS-RTG than

would be enabled by the MMRTG and SRG under the Proposed Action.) Should NASA choose to retain the option to use the GPHS-RTG, DOE would continue with the importation of plutonium-238 from Russia in support of NASA missions. Plutonium fuel fabrication activities in support of NASA and other clients at LANL could continue, as would the RTG assembly and test activities at INL, however, all activities associated with the development and testing of the MMRTG and the SRG qualification unit would not be required. These required activities would be nearly identical to the activities described in Sections 2.1.5, 2.1.6, 2.1.7, and 2.1.9. The amount of plutonium dioxide needed in support of this alternative would depend on how many missions NASA identifies that could use a GPHS-RTG and ultimately how many of these missions select this RTG to meet mission electric power requirements.

2.3 ON-GOING NASA RESEARCH & DEVELOPMENT ACTIVITIES

On-going NASA radioisotope power technology systems and power conversion technology R&D activities encompass research into radioisotope power conversion technologies including efforts that could improve the MMRTG and SRG capability. These activities will not be affected by the decisions either to select the Proposed Action or the No Action Alternative. The power converter technology R&D efforts have applicability to both nuclear and non-nuclear power systems. Included in the radioisotope power technology systems research is R&D for small RPSs that are based on the GPHS and the RHU (see Figures 2-5 and 2-6). NASA will pursue efforts focused on longer-term improvements in radioisotope power conversion technologies that could:

- Increase power conversion efficiency – reducing the quantity of plutonium-238 required per unit power,
- Reduce mass,
- Increase specific power (W/kg),
- Increase reliability, lifetime, and operability,
- Operate in harsh environments,
- Improve multi-mission capability, and
- Increase mission power system flexibility.

NASA is pursuing the development of these potential advances through 1) NASA Research Announcements (NRAs) with private industry and academia for the development of radioisotope power conversion technologies and 2) direct funding of NASA centers for RPS Advanced Technology Development

2.3.1 Radioisotope Power Conversion Technology NASA Research Announcements

The radioisotope power conversion technology development effort encompasses NASA's R&D efforts directed toward improved power conversion technologies that make use of either GPHS modules or RHUs as a heat source. NASA has entered into a series of research agreements with private industry and academic institutions. Under these agreements, the research teams perform fundamental research into power conversion technologies with the goal of developing more efficient and reliable types of RPSs. In the past, NASA has entered into agreements to research advancements in power conversion technologies (see Table 2-6). Over the next several years, it is possible that NASA may enter into additional research agreements as new technologies develop (GRC 2004a).

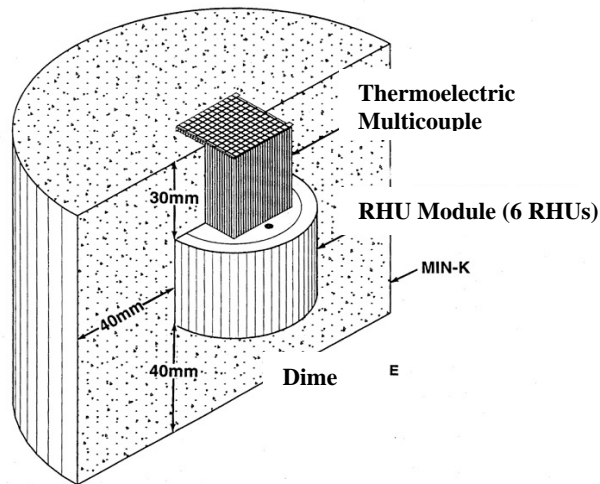


FIGURE 2-5. POTENTIAL RHU-BASED SMALLER POWER SOURCE

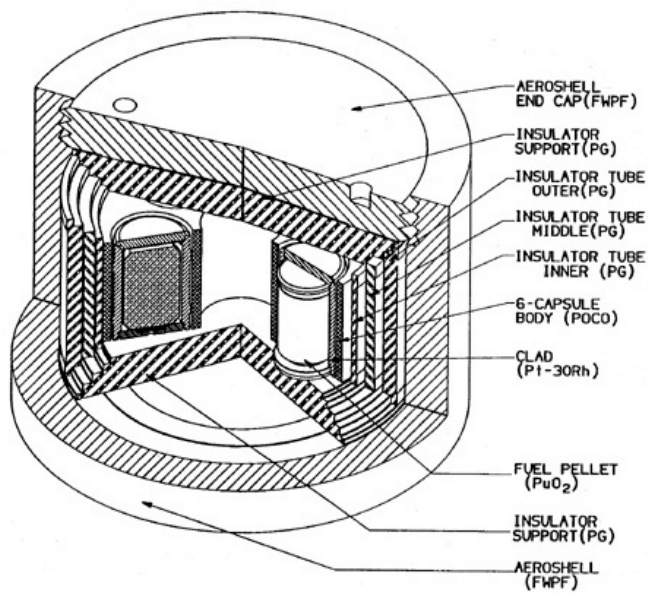


FIGURE 2-6. POTENTIAL RHU-MODULE HEAT SOURCE FOR RHU-BASED SMALLER POWER SOURCE OF FIGURE 2-5

TABLE 2-6. NASA RESEARCH FOR RADIOISOTOPE POWER CONVERSION TECHNOLOGY

Technology	Research Goals
Advanced Thermoelectric Conversion	<p>To improve efficiency, operating ranges, survivability, and flexibility by;</p> <p>Evaluating the advantages of segmenting negative and positive-type thermoelectric materials.</p> <p>Investigating mass optimization.</p> <p>Developing cascaded superlattice based modules, using one or more RHUs, with increased energy conversion efficiencies to produce from a few to several hundred milliwatts of electrical energy.</p> <p>Investigating high temperature operation.</p> <p>Investigating quantum well material technologies.</p>
Advanced Stirling Converters	<p>To evaluate advanced materials, concepts, microfabrication techniques, and analytical techniques to improve converter efficiency while maintaining high reliability.</p>
Thermophotovoltaic Power Conversion	<p>To produce an RPS that combines GPHS with thermophotovoltaic (TPV) power conversion with increased conversion efficiency (as much as a 50% increase over state-of-the-art technology) to produce on the order of 100W_e. Improvements to the performance of 1) PV cells, 2) TPV filters, 3) emitter, and 4) materials required to reduce the thermal radiator size are being investigated.</p>
Brayton Power Converter	<p>To develop and demonstrate an advanced Turbo-Brayton Power System. Initial efforts are to develop a light weight system that will produce 60 to 90 W_e from heat supplied by a single GPHS. The predicted system efficiency is greater than 25%; 36% for deep-space missions.</p>

Source: GRC 2004a

All of these efforts are technology demonstrations and not intended, at this time, to result in the development of a fully qualified RPS. These research efforts use an alternative heat source, typically electrical heaters, and not a radioisotope heat source.

2.3.2 Converter Technology Development at NASA Facilities

In addition to the NRAs, NASA is pursuing improvements to converter technologies through research at both GRC and JPL. The current focus of the effort at GRC is the development of higher efficiency Stirling generators. This could enable development of an SRG with lower mass, improved performance, and higher specific power. A low mass prototype Stirling generator has been developed, and testing has begun (NASA 2004a). The effort at JPL focuses on the development of higher efficiency thermoelectric technologies for potential use in a future RPS design. The research focuses on developing advanced thermoelectric materials that could provide higher overall converter efficiency than currently available with the legacy devices. This approach and advanced designs may also have the potential to reduce mass of these devices. This advanced technology research does not involve the use of the radioisotope heat sources. Alternative heat sources, typically electrical heaters, are used in the research phase.

2.3.3 Facilities Involved

Activities associated with the development, testing, and verification of the power conversion systems (not using plutonium fuel) could be performed at one or more existing facilities including, but not limited to, NASA facilities including GRC at Lewis Field, Cleveland, Ohio and JPL in Pasadena, California; several commercial facilities; and educational institutions. When a heat source is required for any of these activities, an alternative heat source, such as an electric heater, would be used. No radioisotope fuel would be used at these facilities.

2.4 ALTERNATIVES CONSIDERED BUT NOT EVALUATED FURTHER

This section discusses alternatives that were considered but were not evaluated further because these technologies/devices did not fully meet the requirements set forth in Purpose and Need (see Sections 1.2 and 1.3). These alternatives include the consideration of the development of alternative radioisotope power converter technologies for the approximately 100 W_e advanced RPS, the development of alternative converter technologies that would not make use of a radioisotope heat source, and modifying the GPHS-RTG for surface missions where an atmosphere is present.

2.4.1 Alternative Advanced RPS Concepts Including Developing only the MMRTG or the SRG

NASA considered alternative approaches for near-term advanced RPSs : (1) developing a single power system concept rather than both the MMRTG and SRG systems and (2) developing power systems using alternative power conversion technologies (*i.e.*, other than free piston Stirling and flight-qualified thermoelectrics) for use on near-term missions.

The MMRTG and SRG designs were judged most able to meet the schedule demands (*i.e.*, flight ready for a launch in 2009 or 2011) of near-term NASA mission requirements. As such, they were selected for development as part of the Proposed Action. Although the MMRTG is not considered to employ power conversion technology as advanced as others described in this section, the MMRTG represents a "high confidence" solution in that it uses existing GPHS and flight-qualified converter technologies. The SRG represents a class of advanced converter technologies offering significantly higher heat-to-electric power conversion efficiency. Pursuing two advanced RPS designs, rather than one, will potentially provide assurance that NASA will have options for future missions: (1) a power system that has demonstrated capabilities and (2) one that should have higher power conversion efficiency than the RTGs used on past missions. Additionally, the two designs possess characteristics that could make one or the other better suited for specific future missions (see Table 2-4). The Proposed Action to pursue development of both designs, rather than one or the other, is based on the combination of a high confidence design, potential increases in advanced RPS efficiency and creation of flexibility in power system options for future missions.

Alternative technologies considered included the Alkali Metal Thermal to Electric Converter (AMTEC), Thermo-photovoltaic (TPV), and segmented thermoelectric technologies. All of these alternative converter technologies show promise for higher power conversion efficiencies than those available with the previous state-of-the-art flight-qualified SiGe and the PbTe/TAGS thermoelectric converters.

The AMTEC uses sodium (in vapor and liquid form) and a material known as BASE (beta alumina solid electrolyte) to convert heat (from the GPHS) to electricity. NASA and DOE attempted to develop an AMTEC device for space applications and determined that this technology could not be made ready within given parameters. The main issues that needed to be addressed included material thermal compatibility issues and sodium leakage (inadequate seals around the BASE material due to material compatibility and lifetime issues) (NASA 2001).

The TPV devices produce electricity from infrared radiation (heat from the GPHS). To achieve a reasonable efficiency, a large radiator system would be needed to maintain the relatively low temperatures required for efficient TPV cell operation. The size of the radiator, degradation of the TPV cell (a lifetime issue), compatibility with the GPHS module, and space qualified TPV cell materials need further development (NASA 2001).

Segmented thermoelectric technology makes use of the temperature effects to improve the performance of thermoelectric devices. A key issue associated with developing the combination of materials to be used, is to select materials that can be mated together with little electrical resistance while retaining structural integrity of the device (NASA 2001).

The Stirling free piston engine was made a part of the Proposed Action rather than these alternative technologies (*e.g.*, AMTEC, TPV, segmented thermoelectrics) as it was the only advanced power conversion technology considered sufficiently mature to be made flight ready within a reasonable time-frame. The technological issues associated with the development of the RPSs utilizing alternative converter technologies suggested that they could not be developed in time to support NASA's near term exploration goals. However, development efforts for converter technologies not selected to be incorporated into the advanced RPS systems have not been abandoned. As part of their power conversion R&D efforts, NASA will continue to fund the development of alternative power conversion technologies which have the potential to improve the efficiency of future flight power systems

2.4.2 Modified GPHS-RTG

A modified GPHS-RTG design was an option when considering thermoelectric designs for the advanced RPS. NASA, in evaluating the various RPS designs, decided that only one RTG design would be considered for development. The assessment of the potential for successful development resulted in the selection of the MMRTG over other RTG designs, including a modified GPHS-RTG.

The GPHS-RTG used on previous orbital missions, *i.e.*, in the absence of an atmosphere, could be modified for use on surface missions where an atmosphere is present. Potential modifications to the GPHS-RTG would focus on preventing atmospheric contact with internal components susceptible to degradation (such as the multi-foil insulation or thermocouples) or replacing or coating components with materials that would not readily degrade in the atmosphere. While both of these approaches have merit, a number of engineering concerns (including mass and material compatibility) and the need to reinstate manufacturing capabilities, including restarting currently closed production lines, would have to be considered. In addition, a modified GPHS-RTG (producing between 250 and 300 W_e) would not meet NASA's goal of enhanced flexibility in powering missions.

2.4.3 Develop Only Non-Radioisotope Power Systems

Several respondents to the Notice of Intent (69 FR 21867) suggested that NASA not develop advanced RPSs and instead use only solar or other non-nuclear power sources for future solar system exploration. Solar energy has been used for most U.S. space applications, and it is usually the preferred choice of mission planners because they are typically readily available and easier to incorporate into a mission than RPS-powered devices. However, for many solar system exploration missions the current state of solar power technology is not adequate. For example, for the deep-space Cassini mission, the weight of the solar array would have made launch impossible with existing launch vehicles and control of the massive solar panels untenable if launch hurdles could have been overcome (NASA 1997). Similar technical barriers faced planners for the proposed Pluto New Horizons mission, and the use of solar power was determined not to be feasible (NASA 2005c).

Yet the use of solar power and further development efforts have not been abandoned; NASA will continue to consider solar power as an option for any future missions. For example, the current Mars rovers, Spirit and Opportunity, rely on solar panels for primary power supplemented by batteries and the proposed New Frontiers Juno mission to Jupiter will use solar power. Research continues on a host of advanced solar power technologies: high efficiency solar cells, solar concentrators, low-intensity low-temperature solar cells, solar-driven Stirling or Brayton converters, and solar collector technology. These technologies are intended to address the limitations identified by NASA for solar power use on extended Mars surface exploration and for missions to the outer planets.

For missions to the outer planets these limitations include:

- Decreased effectiveness as distance from sun increases (need for large solar arrays for missions to outer planets),
- Large structures impact the ability of spacecraft to perform mission
 - obstruction of view
 - difficulty in orienting the spacecraft,
- Need to orient solar array toward sun most of the time, and
- Degradation in high radiation environments.

When considering solar power for an extended Mars surface mission, NASA identified the following limitations:

- Intermittent Operation,
- Limited lifetime due to system degradation from dust,
- Battery cycle life,
- Seasonal variations in solar incidence,
- Interruption of power production by dust storms,
- System inoperability at certain locations (*i.e.*, in canyon shadows).

2.5 COMPARISON OF ALTERNATIVES INCLUDING THE NO ACTION ALTERNATIVE

This section summarizes and compares the potential environmental impacts of the Proposed Action and the No Action Alternative. The anticipated impacts associated with implementation of the Proposed Action and the No Action Alternative are presented in Tables 2-7 and 2-8.

Table 2-7 compares the Proposed Action and the No Action Alternative from an overall, programmatic perspective. Potential impacts from the near-term and long-term perspective are provided. The long-term perspective is included to address the potential for impacts associated with reasonably foreseeable future actions, but is not within the scope of this DPEIS. Table 2-8 provides a comparison of potential environmental impacts in implementing the Proposed Action or the No Action Alternative.

Implementation of the Proposed Action would entail the fabrication and manufacture of the advanced RPSs. Fabrication and manufacture of the advanced RPSs would be undertaken at government and commercial facilities, where such actions would be considered routine and within the normal scope of activities at these facilities.

Under the No Action Alternative, NASA would continue to plan missions with the GPHS-RTG as a viable alternative for the mission power supply. However, implementing the No Action Alternative would entail restarting the GPHS-RTG production line. DOE could continue to fabricate the GPHS fuel at LANL and assemble and test the GPHS and GPHS-RTG at INL. Long-range R&D activities discussed in Section 2.3 will continue. The GPHS-RTG has been manufactured for well over 20 years, and the environmental impacts associated with its production are well known.

The RPS production requirements for NASA are only a part of the DOE mission with regards to RPS production. Therefore, the types of impacts at DOE sites associated with RPS production would be incurred regardless of NASA's decision to pursue development of advanced RPS designs. Therefore, it is anticipated that the existing conditions and potential environmental impacts at the respective sites (LANL and INL) would mostly remain unchanged with implementation of either the Proposed Action or the No Action Alternative.

TABLE 2-7. COMPARISON OF POTENTIAL IMPACTS OF ALTERNATIVES – PROGRAMMATIC PERSPECTIVE

	Potential Impacts of Implementing the Proposed Action	Potential Impacts of the No-Action Alternative ^{1,2}
Development and Production of MMRTG and SRG, including:		
R&D on MMRTG and SRG advanced RPS power converter concepts	No substantial impacts associated with ongoing R&D in existing NASA, university, and commercial facilities	None
Testing of advanced RPS power converters at full power (without radioisotope fuel) to simulate to the extent practicable, space conditions including operation in a vacuum	Minor impacts associated with R&D at existing NASA, university, and commercial facilities; some modifications and/or expansion of facilities may be required	None - Possible testing of modifications to the existing GPHS-RTG
Importing and transporting PuO ₂ from Russia to LANL	Radiological dose from importing up to 40 kg (less than 10 kg would be required for the Proposed Action): to transportation workers-2.6 person-rem; to the public-4.5 person rem; or 1.1×10^{-3} and 2.3×10^{-3} latent cancer fatalities, respectively. Accident risks 1×10^{-4} latent cancer fatalities among workers and the public from transportation accidents associated with the importation.	Impacts would be similar to Proposed Action ^{1,3}
Purification and encapsulation of fueled clads at LANL or at INL	<p>LANL national security and space related plutonium-238 fuel pellet fabrication operations:</p> <p>Very, very small releases (on the order of 1×10^{-8} curies per year) to the environment with an estimated 1.8×10^{-5} person-rem/yr (or 3.8×10^{-7} latent cancer fatalities over the 35 year operating life) and the maximally exposed member of the public dose of 1×10^{-9} rem/yr.</p> <p>Workers: 19 person-rem/yr with an average worker dose of 0.24 rem/yr.</p> <p>Accident risks: a maximum annual cancer risk of 2.5×10^{-4} for the surrounding population).</p> <p>Radiological risks to the public associated with accidental releases from RPS related activities also are a small contributor to the overall risks associated with operations at the site. Worker exposures from some accidents could be in excess of occupational dose limits for some site workers.</p> <p>Radiological Wastes: about 13 cubic meters of transuranic waste and 150 cubic meters of low-level radioactive wastes per year.</p>	Impacts would be similar to Proposed Action ^{1,4}

**TABLE 2-7. COMPARISON OF POTENTIAL IMPACTS OF ALTERNATIVES – PROGRAMMATIC PERSPECTIVE
(CONTINUED)**

	Potential Impacts of Implementing the Proposed Action	Potential Impacts of the No-Action Alternative ^{1,2}
Assembly and testing of radioisotope fueled advanced RPS qualification units at INL	INL national security and space related plutonium-238 RPS assembly operations: No expected releases ⁷ (with an estimated 1.7×10^{-6} person-rem/yr (or 3.5×10^{-8} Latent Cancer Fatalities over the 35 year operating life) and the maximally exposed member of the public dose of 1.4×10^{-10} rem/yr). Workers: 1.2 person-rem/yr with an average worker dose of 1.7×10^{-2} rem/yr. Accident risks: a maximum annual cancer risk of 2.6×10^{-3} for the surrounding population. Radioactive wastes: a minimal amount of transuranic waste and 1 cubic meter of low-level radioactive wastes per year.	Negligible radiological impacts to the public from normal operations and potential accidents
Advanced RPS Safety Testing Activities	Testing with fuel simulants, if needed, no substantial impacts, could result in minor radiological impacts.	No substantial impacts - Possibly minor if additional testing of GPHS-RTGs is required at DOE facilities
Development of Advanced Converter Technology, including:		
R&D on specific advanced RPS power converter concepts (without radioisotope fuel)	No substantial impacts ⁵ associated with ongoing R&D at existing NASA, university, and commercial facilities	Same as the Proposed Action
Testing of the advanced power converter at full power (without radioisotope fuel) to simulate to the extent practicable, space conditions including operation in a vacuum	No substantial impacts ⁵ associated with R&D at existing NASA, university, and commercial facilities; some modifications and/or expansion of facilities may be required	Same as the Proposed Action
Reasonably Foreseeable Future Actions^{2,6}:		
Importing and transporting PuO ₂ from Russia to LANL	See same section above under Development and Production of MMRTG/SRG ^{3,6} . Impacts would be similar.	Impacts would be similar to Proposed Action ^{1,3}
Purification and encapsulation of fueled clads at LANL or at INL	See same section above under Development and Production of MMRTG/SRG ^{4,6} . Impacts should be similar.	Impacts would be similar to Proposed Action ^{1,4}
Assembly and testing of radioisotope fueled advanced RPS qualification units at INL	See same section above under Development and Production of MMRTG/SRG. Impacts would be similar.	Negligible radiological impacts to the public from normal operations and potential accidents.

**TABLE 2-7. COMPARISON OF POTENTIAL IMPACTS OF ALTERNATIVES – PROGRAMMATIC PERSPECTIVE
(CONTINUED)**

	Potential Impacts of Implementing the Proposed Action	Potential Impacts of the No-Action Alternative^{1,2}
Advanced RPS Safety Testing Activities	No substantial impacts - Possibly minor if additional testing is required at DOE facilities	No substantial impacts - Possibly minor if additional testing of GPHS-RTGs is required at DOE facilities
R&D on specific power converter concepts	No substantial impacts ⁵ associated with R&D at existing NASA, university, and commercial facilities	Same as the Proposed Action
Testing of the advanced power converters at full power (with radioisotope fuel) to simulate to the extent practicable, space conditions including operation in a vacuum	No substantial impacts ⁵ associated with additional longer-term operation of test facility Impacts associated with: Importing plutonium, Fueled clad production, RPS assembly and test	Same as the Proposed Action
Launch and mission operation	No long term impacts from normal launch. Impacts dissipate soon after launch. Accident risks addressed in mission-specific NEPA analysis and documentation	Same as the Proposed Action

1. Overall demand for Pu-238 and corresponding impacts depend upon the number of GPHS-RTG missions identified. Overall production and use would not exceed the production rates identified in DOE's Consolidation EIS (DOE 2005a).
2. The DOE NEPA process for the consolidation of plutonium operations for the production of RPSs is ongoing (DOE 2005a). Impacts presented in the table are for the No Action Alternative.
3. Under the Proposed Action of DOE's Consolidation EIS (DOE 2005a) the shipment of Russian plutonium would be to INL instead of LANL as under the No Action Alternative in that EIS.
4. Under the Proposed Action of DOE's Consolidation EIS (DOE 2005a) fueled clad production occurs at INL. Impacts at INL would be similar to those at LANL under the Proposed Action.
5. These activities are the subject of a Categorical Exclusion determination.
6. Overall demand for Pu-238 and corresponding impacts depend upon the type and number of RPSs used. Overall production and use would not exceed the production rates identified in DOE's Consolidation EIS (DOE 2005a).
7. These consequences are the result of all Pu-238 RPS-related activities at INL.

TABLE 2-8. COMPARISON OF POTENTIAL IMPACTS OF ALTERNATIVES – ENVIRONMENTAL MEDIA

Impact Category	Implementation of the No Action Alternative	Implementation of the Proposed Action
Land Resources	No changes to land use and no adverse impacts to land resources are anticipated at any project site.	Same as the No Action Alternative
Air Resources – Non Radiological	No long-term impacts are anticipated at any project site. Air pollutant releases are anticipated to be within permitted limits.	Same as the No Action Alternative
Air Resources - Radiological	Some release of radioactive air pollutants at LANL, in the range of microcuries of plutonium-238. No impacts are anticipated at other project sites.	Same as the No Action Alternative
Water Resources	No change to existing water usage is expected at any project site.	Same as the No Action Alternative
Ambient Noise	No change to existing conditions at any project site. Noise levels are expected to be within prescribed ranges.	Same as the No Action Alternative
Geology and Soils	No change to existing conditions at any project site. No adverse impacts are anticipated.	Same as the No Action Alternative
Biological Resources	No change to existing conditions at any project site.	Same as the No Action Alternative
Socioeconomics	No long-term impacts are anticipated. Minor increase in economic activities at the project areas is possible.	Same as the No Action Alternative
Cultural Resources	No adverse impacts are anticipated at any project site.	Same as the No Action Alternative
Hazardous and Radioactive Waste	Slight increase to hazardous waste quantities at project sites. Slight increase in radioactive waste limited to LANL.	Same as the No Action Alternative
Transportation of Radioisotope Components	Health risks from normal transport and accidents is expected to be less than 1 latent cancer fatality.	Same as the No Action Alternative
Human Health	No nonradiological health impacts are anticipated. See Table 2-7 for radiological impacts to workers and public at LANL and INL.	Same as the No Action Alternative

NOTE: The impacts identified in this table are those from the implementation of the Proposed Action or the No Action Alternative including, for both of the alternatives, the potential environmental impacts of RPS production for actual space missions. If the environmental impacts associated with RPS production for actual space missions are not included, there are no impacts for the impact categories of Air Resources - Radiological, Radioactive Wastes, Transportation of Radioisotope Components, and Human Health under the No Action Alternative.

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3 DESCRIPTION OF THE AFFECTED ENVIRONMENT

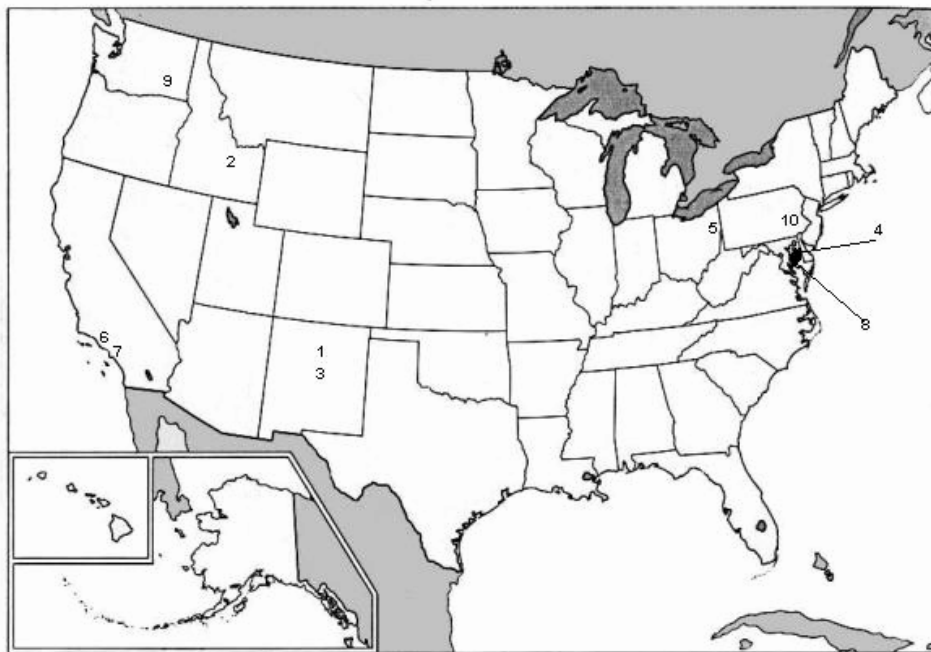
This chapter provides a summary of the environment at U.S. Government and commercial facilities where development, fabrication, assembly, testing, and verification would occur. The development of the advanced Radioisotope Power Systems (RPS) would occur in parallel with the ongoing operations at the U.S. Department of Energy (DOE) facilities associated with the processing and fabricating of non-weapons grade plutonium-238 (Pu-238) dioxide fuel. Fabricating the fuel and developing, assembling, testing, and safety testing the completed advanced RPSs would occur only at government facilities. Development of the power conversion systems would occur at a combination of government and commercial facilities. See Table 3-1 for a list of government and commercial facilities and the anticipated activities of each organization. Figure 3-1 provides the locations of these facilities.

The affected environment for the DOE facilities have been thoroughly addressed in the DOE's existing and approved National Environmental Policy Act of 1969, as amended (NEPA) documentation for the respective facilities/sites. These documents are briefly summarized by NASA in Sections 3.1 through 3.3. Sections 3.4 through 3.7 address the affected environment at other government, NASA, and commercial facilities. Though no space launches with advanced RPSs would occur under this Draft Programmatic Environmental Impact Statement (DPEIS), it is reasonable to believe that should NASA proceed with the Proposed Action and the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and/or the Stirling Radioisotope Generator (SRG) are ultimately developed, missions that could use the advanced RPS would be developed. Such actions would be the subject of additional NEPA documentation.

The affected environments at the government facilities cited in this DPEIS have been discussed in NEPA, documents and other institutional documents such as the Integrated Natural Resources Management Plan (INRMP) and the Environmental Resources Document (ERD) for the respective facilities. The following documents were used as primary sources to summarize the affected environments at the respective facilities. The *Site-Wide EIS for the Continued Operations of the Los Alamos National Laboratory* (DOE 1999a); the *Advanced Mixed Waste Treatment Project Final EIS* (DOE 1999b); the *Final Sandia National Laboratory Site-Wide EIS* (DOE 1999c); the *Final Programmatic EIS for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the U.S., including the Role of the Fast Flux Test Facility* (DOE 2000); the *Final Environmental Assessment for the Future Location of Heat Source/Radioisotope Power System Assembly and Testing and Operations Currently Located at the Mound Site* (DOE 2002b); the *Idaho High-Level Waste and Facilities Disposition Final EIS* (DOE 2002c); and the *Draft Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to Production of Radioisotope Power Systems – Draft Consolidation EIS* (DOE 2005a) were used for the DOE facilities. The Final INRMP for the U.S. Army's Aberdeen Proving Ground (APG) (DOD 2001b) was used for that facility. The ERDs for the Glenn Research Center (GRC 2005) and the Jet Propulsion Laboratory (JPL 2002) were used for those facilities.

TABLE 3-1. ADVANCED RPS ACTIVITIES AND ASSOCIATED FACILITIES

Entity		Facility Location	Activities
Government Facilities	DOE	1. Los Alamos National Laboratory (LANL), Los Alamos, New Mexico.	Process and fabricate Pu-238 fuel.
		2. Idaho National Laboratory (INL), Idaho Falls, Idaho.	Assemble and test advanced RPSs.
		3. Sandia National Laboratory (SNL), Albuquerque, New Mexico.	Test simulant-fueled advanced RPSs.
	DOD/Army	4. Aberdeen Proving Ground (APG), Aberdeen, Maryland.	
	NASA	5. Glenn Research Center (GRC), Cleveland, Ohio.	
		6. Jet Propulsion Laboratory (JPL), Pasadena, California.	
Commercial Facilities		7. Pratt & Whitney Rocketdyne, Canoga Park, California.	
		8. Teledyne Energy Systems, Hunt Valley, Maryland.	
		9. Infinia Corporation, Kennewick, Washington.	
		10. Lockheed Martin, King of Prussia & Newtown, Pennsylvania.	



Note: Refer to Table 3-1 for location numbers

FIGURE 3-1. LOCATIONS OF FACILITIES

3.1 LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NEW MEXICO

The affected environment for Los Alamos National Laboratory (LANL) is described in detail in existing DOE NEPA documentation, *e.g.*, the Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication (DOE 1991), the Site-Wide Environmental Impact Statement for Continued Operation of the Los Alamos National Laboratory (DOE 1999a), and the Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to the Production of Radioisotope Power Systems (DOE 2005a), which bounds the activities at the facility supporting the Proposed Action of this DPEIS. NASA's summary of those documents is found below and is incorporated by reference. Current plutonium-238 operations include fabricating and encapsulating the plutonium-238 pellets; storage of oxide, storage of scrap, and storage of waste from the Cassini mission; and preparations for operation of a new aqueous scrap processing system for plutonium-238 materials for future missions. NASA's summary of those documents is found below.

The area encompassed by the LANL is divided into separate areas called Technical Areas (TA). TA-55, the plutonium handling facility is located in a secure area in the west-central portion of LANL. Plutonium-238 operations are performed in building TA-55-4. TA-55 provides research and applications in chemical and metallurgical processes for recovering, purifying, and converting plutonium and other actinides into many compounds and forms, as well as research into material properties and fabrication of parts for research and stockpile applications. Plutonium-238 operations include fabricating and encapsulating the plutonium-238 pellets for the GPHS modules; storage of oxide, scrap, and waste from past missions; and preparations for operation of a new aqueous scrap processing system for plutonium-238 materials for future missions (DOE 2005a).

3.1.1 Land Resources

The LANL is approximately 10,716 hectares (ha) (26,480 acres (ac)) in area and is located north-northeast of Albuquerque, New Mexico and occupies about 86 percent of Los Alamos County with the remaining area in Santa Fe County. The region has a diverse ecosystem characterized by forested areas with mountains, low-lying meadows, mixed grass, shrubs, savannah land, canyons, cliffs, and valleys with the Rio Grande Valley as the eastern border about 1,981 meters (m) (6,500 feet (ft)) above sea level and the Pajarito Mountain as the western border about 3,048 m (10,000 ft) above sea level. Land use at LANL is managed as technical areas with buildings, structures, utilities, and roadways. Land use is categorized as support facilities, research and development (R&D), R&D/waste disposal, explosives, explosives/waste disposal, and buffer (DOE 2005a).

The LANL is a multidisciplinary, multipurpose institution involved in theoretical and experimental R&D activities in national problems in energy, environment, infrastructure and health security, including design and development of nuclear weapons (DOE 1999a).

3.1.2 Air Resources

Climate: The climate at Los Alamos can be characterized as semi-arid, temperate mountain climate with annual precipitation ranging from 25 to 51 centimeters (cm) (10 to 20 inches (in)) and annual temperature ranging from about 17.4 to 80.6 degrees Fahrenheit (°F) (-8 to 27 degrees Celsius (°C)). Over one-third of the annual precipitation occurs from thundershowers in July and

August. About 150 cm (59 in) of snow falls annually during the winter months. Wind speeds vary during the year with an average speed of about 11.3 kilometers per hour (km/hr) (7 miles per hour (mph)) (DOE 2005a).

Non-Radiological Air Quality: Air quality is regulated through the National Ambient Air Quality Standards (NAAQS) promulgated under the CAA, as amended (42 U.S.C. 7401 *et seq.*). Under NAAQS, Federal primary and secondary air quality standards are established for six criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO₂), ozone (O₃), particulate matter (PM₁₀/PM_{2.5}), and sulfur dioxide (SO₂). Primary standards set limits to protect public health, including the health of sensitive populations such as asthmatics, children and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings from any known or anticipated adverse effects of a pollutant (EPA 2004a).

Air quality in New Mexico is controlled on a regional basis and parameters such as climate, meteorology, topography, vegetation, land use, population, and growth projections are considered when setting air quality control regions. An air quality control region may include whole or parts of counties. LANL is in the Upper Rio Grande Valley Intrastate Air Quality Control Region and this region includes all of Los Alamos, Santa Fe, and Taos Counties and a portion of Rio Arriba County (NMED 2004b). Air quality at LANL is classified as in attainment or unclassifiable with respect to the NAAQS (EPA 2005; EPA 2004c). LANL has an approved CAA Title V Operating Permit from the New Mexico Environment Department (DOE 2005a; NMED 2004a).

Radiological Air Quality: All room air from the plutonium processing areas flows through two banks of high efficiency particulate air (HEPA) filters before being discharged and is continuously sampled after the final HEPA filter; the exhaust from the glove box line flows through four stages of HEPA filters. For 2003, the plutonium emissions from LANL as a whole were 4.87×10^{-6} curies of which 1.55×10^{-6} curies came from TA-55 (DOE 2005a).

3.1.3 Water Resources

In 2003, LANL used about 1.4 billion liters (l) (378 million gallons (gal)) of water. Water for all purposes is supplied from the main aquifer (DOE 2005a).

Surface Water: Surface waters at LANL drain toward the Rio Grande River to the east. Most surface water features occur as short-lived or intermittent streams and may be lost by evaporation, transpiration, and infiltration before reaching the Rio Grande River with the exception of runoff from heavy thunderstorms and heavy snowmelt. Surface water features that have continuous flow at LANL only support wildlife and are not used for municipal, industrial, or irrigation uses (DOE 2005a).

Effluents from LANL are comprised of sanitary wastewater, wastewater from industrial processes, and storm water. Effluent discharges occur under National Pollutant Discharge Elimination System (NPDES) permits (DOE 2005a).

Buildings, facilities, and structures at LANL that are located within the 100- or the 500-year floodplain are characterized as moderate hazard, low hazard, or no hazard. Buildings in the floodplains that contain sealed radioactive sources in equipment are characterized as moderate hazard (DOE 1999a).

Groundwater: A main aquifer and perched aquifers (aquifers created above the groundwater level when the descent of water percolating from above is blocked by a shelf of impermeable rock) occur near the surface at LANL. Groundwater use has led to decline in water levels in the wells as pumping and natural discharges have exceeded recharge and inflow. Groundwater generally flows to the east toward the Rio Grande River. Groundwater appears on the surface as springs in many places at LANL (DOE 1999a).

Los Alamos County owns and operates a network of groundwater monitoring and supply wells and is responsible for supplying water to LANL and surrounding communities. Activities at LANL resulting in discharge of effluents have impacted groundwater, and some contaminants have exceeded regulatory limits. LANL has instituted an effluent treatment system that has made improvements in the effluent discharges, which now meet or are below regulatory requirements (DOE 2005a).

3.1.4 Ambient Noise

In general, noise levels measured at the LANL boundary ranged from 31 to 51 a-weighted decibels (dBA) (DOE 1999a).

3.1.5 Geology and Soils

Geology: The Rio Grande Rift is a major geologic feature in the region. The Pajarito Fault System in Los Alamos County, comprised of the Pajarito Fault, the Rendija Canyon Fault, and the Guaje Mountain Fault, lies within the Rio Grande Rift and is immediately to the north and west of LANL. The Pajarito Fault System could produce earthquakes of about magnitude seven on the Richter scale, which could cause considerable damage to structures and underground pipes. An earthquake of this magnitude is estimated to occur once in 100,000 years. Historical records have indicated six earthquakes have occurred in the LANL area with a magnitude of five or greater. The most significant seismic event was a 5.5 magnitude earthquake that occurred southeast of LANL in 1918. Numerous earthquakes of magnitude 4.5 or less have occurred in the recent past in the LANL area. The DOE has a requirement that facilities be designed, constructed, and operated to protect the public, workers, and the environment from natural hazards such as earthquakes. Maintenance and refurbishment activities at LANL are specifically intended to upgrade the seismic performance of older structures (DOE 2005a).

Soils: Several distinct well-drained soils have developed at LANL. Included, among others, are ash-flow deposits, volcanic debris, pumice, clays, gravels, basalts, and localized deposits of terrestrial conglomerates, sandstones, mudstones, and limestones (DOE 1999a). There are no designated prime farmland soils at LANL (DOE 2005a).

3.1.6 Biological Resources

Landform, a 1,500 m (5,000 ft) elevational gradient, and climate contribute to a diverse ecosystem at LANL characterized by grasslands, wetlands, shrublands, woodlands, and mountain forests providing habitats for many animal species. Animals commonly found include elk, deer, bears, mountain lions, coyotes, rodents, bats, reptiles, amphibians, invertebrates, and many resident and migratory birds. No species of fish have been found at LANL. Storm water and effluent outfalls have contributed to the existing wetlands acreage (a total of 20 ha (50 ac)), a potential source of drinking water for large mammals (DOE 1999a).

Threatened or Endangered Species: The Federally listed threatened or endangered bald eagle (*Haliaeetus leucocephalus*), black-footed ferret (*Mustella nigripes*), southwestern willow flycatcher (*Empidonax traillii extimus*), and Mexican spotted owl (*Strix occidentalis lucida*) could reside on LANL. An additional 24 bird, mammal, amphibian, or insect species that are Federally listed species of concern may reside on LANL (DOE 2005a; FWS 2004). The state of New Mexico has listed a total of 25 birds, mammals, amphibians, or plants, including the above species, as threatened, endangered, sensitive, or of concern that could occur at LANL. There are three wetlands located within TA-55 that may be used by four bird species on both State and Federal lists: the northern goshawk, the Mexican spotted owl, the spotted bat, and the southwestern willow flycatcher (DOE 2005a). A habitat management plan for listed species has been prepared for LANL (60 FR 53588).

3.1.7 Socioeconomics

In 2003, LANL employed 12,975 persons in various fields that support the activities at LANL. Over 89 percent of these employees lived in Los Alamos, Rio Arriba, and Santa Fe counties. The government represented the largest sector of employment in these three counties in 2003, followed by trade, utilities, transportation activities, leisure, and hospitality. LANL employed over 12 percent of the workforce in the tri-county area in 2003 (DOE 2005a). LANL is responsible for about \$3.4 billion or 30 percent of the economic activity (in FY 1995) in these three counties by way of wages, salaries, and purchase of goods and services. LANL is directly or indirectly responsible for the employment of over 27,200 people representing 32 percent of total employment in these three counties (DOE 1999a).

In 2000, population in Los Alamos, Rio Arriba, and Santa Fe counties was 188,825 persons, an increase of about 24.7 percent from 1990. During the same period, New Mexico population increased by about 20 percent, to 1,819,046 persons (DOE 2005a; USCB 2004).

3.1.8 Cultural Resources

A large number of prehistoric and historic archeological sites as well as traditional cultural properties (*e.g.*, ceremonial sites, natural features, ethno-botanical sites) used by American Indian and Hispanic communities are present at LANL. Many of these sites could be potentially eligible for listing in the National Register of Historic Places (NRHP). Some of these sites are also listed on the State Register of Cultural Properties (DOE 1999a). The Bandelier National Monument, the Puye Cliffs Historic Ruins, and the Los Alamos Scientific Laboratory National Historic District, all in the vicinity of LANL have been established as NRHP sites or districts (DOE 2005a).

Areas that are important to Native American tribes are called traditional cultural properties. Such areas have been identified on LANL. Consultations with stakeholders with regard to these areas are ongoing (DOE 2005a).

3.1.9 Hazardous and Radioactive Waste

Waste management at LANL is accomplished by using appropriate treatment, storage, and disposal technologies, and in compliance with all applicable Federal and State statutes and DOE Orders. LANL manages transuranic waste, mixed transuranic waste, low-level radioactive waste, mixed low-level radioactive waste, hazardous waste, and nonhazardous waste. In 2003, LANL generated 5,625 cubic meters (m³) (198,618 cubic ft (ft³)) of low-level radioactive waste;

36 m³ (1,271 ft³) of mixed low-level radioactive waste; 560 m³ (19,773 ft³) of transuranic and mixed transuranic waste; 689 metric tons (759 tons) of hazardous waste; 794,253 m³ (28 million ft³) of non-hazardous liquid waste; and 10,280 metric tons (11,331 tons) of non-hazardous solid waste. In addition to the yearly waste generation, LANL has also stored 759 m³ (27,096 ft³) of mixed low-level radioactive waste. Waste is stored, treated, or disposed onsite, or transported for offsite disposal (DOE 2005a).

Past discharges of treated and untreated wastes, discharges from the Radioactive Liquid Waste Treatment Facility (RLWTF), leaks from a reactor, and sanitary wastewater releases have contributed to groundwater contamination. Contaminants such as strontium-90, tritium, americium-241, cesium-137, plutonium-238/239, nitrates, metals, volatile organic compounds, and high explosives have been measured above regulatory levels in perched aquifers and the main aquifer (DOE 1999a).

Any hazardous or radioactive mixed wastes associated with operations are handled in accordance with Resource Conservation and Recovery Act (RCRA) guidelines.

3.1.10 Transportation of Radioisotope Components

Packaging: DOE has established requirements and guidelines that comply with Department of Transportation (DOT) regulations for transporting radioisotopes as well as encapsulation of radioisotopes and associated hardware for transportation. The Pu-238 transportation containers consist of a cask/cage assembly, an aluminum thermal shield, heat dissipating system, and stainless steel primary and secondary containment vessels. These vessels are designed to withstand all pressure buildups that could occur during normal conditions of transport and hypothetical accident conditions (DOE 2003a).

Transportation: DOE uses a Secure Transportation System to transport radioisotopes. These transport systems include tie-down equipment, temperature monitoring, fire alarms, and access denial systems. The vehicles undergo extensive checks prior to each trip as well as periodic maintenance checks (DOE 2002b).

3.1.11 Human Health

In 2003, approximately 2.8% (60.2 curies) of the total release of airborne radionuclides at LANL was attributed to TA-55. Current regulations limit the dose resulting from releases of airborne radioactivity from DOE facilities to no more than 10 millirem (mrem) per year to a member of the general public. For perspective, a modern chest x-ray results in a dose of about 6 mrem and about 65 mrem is received from a diagnostic pelvic and hip x-ray (DOE 2000).

Radiation sources from LANL account for only about one percent of the total radiation contributions to the maximally exposed individual for LANL from all man-made and natural sources (DOE 1999a). From LANL operations, the offsite total annual dose for the maximally exposed individual is 0.65 mrem and the onsite maximally exposed individual dose is 2.5 mrem (LANL 2004).

Worker Radiation Exposure from Past and Ongoing Pu-238 Operations

During past periods of high levels of production in the plutonium-238 production line for RHUs and fueled clads for the general purpose heat source (GPHS) modules, radiation exposures to the

glove box workers involved in the production were below the DOE limit of 5 rem (1 rem = 1000 mrem). In 2003, the average individual worker dose at LANL was 117 mrem (DOE 2005a).

3.2 IDAHO NATIONAL LABORATORY, IDAHO FALLS, IDAHO

The affected environment for Idaho National Laboratory (INL) is described in detail in existing DOE NEPA documentation, *e.g.*, the Draft Consolidation EIS (DOE 2005a), which bounds the activities at the facility supporting the Proposed Action of this DPEIS. NASA's summary of that document is found below and is incorporated by reference. At the time of the relocation of the RPS activities from the DOE Mound facility in Ohio to the INL site, the area housing the RPS activities at INL was referred to as the Argonne National Laboratory – West (ANL-W) (now called the Materials and Fuels Complex (MFC)) and was part of the Idaho National Engineering and Environmental Laboratory complex. DOE has subsequently integrated these sites and they are now known as INL.

Assembly and testing of the MMRTG and SRG would occur at the Space and Security Power Systems Facility at the MFC. The Space and Security Power Systems Facility consists of several facilities and is located within a security-protected area. Assembly and testing activities associated with advanced RPSs would be performed in glove boxes using inert gasses. Glovebox gasses would be vented to the atmosphere via HEPA filters. Closed circuit cameras are located throughout the facility and connected to the monitors in the control room (DOE 2002b).

3.2.1 Land Resources

The Space and Security Power Systems Facility is located on the southeast side at the 230,700 ha (570,000 ac) INL complex, west of Idaho Falls, Idaho. Most of INL is located in the eastern portion of Butte County but also extends to the counties of Bingham to the south and southeast, Jefferson to the northeast, Bonneville to the southeast, and Clark to the north. Ninety-eight percent of INL is undeveloped and generally consists of sagebrush steppe and native grasses. The undeveloped areas act as safety and accident buffer zones and are used for environmental research, ecological preservation, socio-cultural preservation, and livestock grazing. Land use at INL primarily resembles a commercial/industrial site with facilities, open space, and roads (DOE 2002b; DOE 2000; DOE 1999b).

The complexes at INL are used in R&D activities on reactor performance, materials testing, environmental monitoring, natural resources research and planning, and waste processing (DOE 2000). The Space and Security Power Systems Facility occupies approximately 20 ha (50 ac) that include reactor buildings, laboratories, warehouses, spent fuel storage, tank areas, administrative buildings, and wastewater treatment and disposal facilities associated with nuclear power research (DOE 2005a; DOE 2002b).

3.2.2 Air Resources

Climate: The climate at the INL complex can be characterized as semiarid steppe with low humidity, with an annual average temperature of about 42° F (5.5° C), and an annual average precipitation of 22 cm (8.7 in). Prevailing winds are southwest or northeast with an annual average wind speed of 12 km/hr (7.6 mph) (DOE 2005a).

Air Quality: Air quality is regulated through the NAAQS promulgated under the CAA. See Section 3.1.2 for additional discussion on primary and secondary air quality standards and criteria pollutants.

Air quality at the INL complex and the surrounding counties is considered in attainment or unclassifiable with respect to the NAAQS and the Idaho State Ambient Air Quality Standards. The DOE has modeled concentrations of criteria pollutants for the INL facility. These models are considered to be conservative and the results were well below regulatory standards (DOE 2005a; EPA 2005; EPA 2004c).

3.2.3 Water Resources

In general, the INL complex utilizes about 4,200 million l (1,100 million gal) of water per year from the Snake River Plain aquifer, its only source of water. Annual water usage at MFC is approximately 182 million l (48 million gal) (DOE 2005a).

Surface Water: Three intermittent streams, Big Lost River, Little Lost River, and Birch Creek, drain the mountain areas north and west of the INL complex to a closed drainage basin called the Mud Lake-Lost River Basin within INL. Surface water from these streams reaching INL either infiltrates and recharges the aquifer or is lost to evaporation; no outflow from INL occurs. The State has classified these streams for agricultural purposes, development of cold-water biota, salmon spawning, and for recreation. Water is not used from the streams for potable purposes and no effluents are routinely discharged from facilities to these streams; minor discharges including storm water runoff occur under the NPDES permit conditions. These streams are not classified as wild and scenic rivers. Other surface water bodies at INL include natural wetland-like ponds and human-made percolation and evaporation ponds (DOE 2000).

The MFC has no surface water or natural wetland areas other than the industrial waste pond to treat the industrial wastewater and the sewage treatment lagoon to treat effluent wastewater. Wastewater discharge occurs under the NPDES. MFC is not located within a floodplain-prone area (DOE 2005a).

Groundwater: The Snake River Plain aquifer, classified by the Environmental Protection Agency (EPA) as Class 1 (sole source for drinking water/ecologically vital), lies 60 to 300 m (200 to 1,000 ft) below the INL complex. It is estimated to contain 1.2 to 2.5 quadrillion l (317 to 660 trillion gal) of water, extends about 2.5 million ha (6.1 million ac) in southeastern Idaho, and is the primary source of drinking water in the Snake River Basin. Groundwater recharge occurs via the Snake River, Big/Little Lost Rivers, Birch Creek, rainfall, and snowmelt. Most of the water used at INL is returned to the subsurface via percolation ponds (DOE 2000).

3.2.4 Ambient Noise

Industrial facilities, operation of equipment and machinery, and transportation are contributing sources of noise at the INL complex. The average day-night sound levels are in the 35 to 50 dBA range at the INL boundary, typical for a rural location. The MFC is 7 km (4.3 mi) from the nearest site boundary; the noise levels experienced at the boundary from the industrial facilities are not measurable or indistinguishable from background levels (DOE 2005a).

3.2.5 Geology and Soils

Geology: The INL complex is on the northwestern edge of the Eastern Snake River Plain, a relatively flat area. Two tectonic faults lie within proximity of the INL complex: the Arco Segment of the Lost River Fault to the west and the Howe Segment of the Lemhi Fault to the northwest. The Snake River Plain is a fairly stable area with low seismic activity; relatively few, minor earthquakes of up to 3.6 magnitude (Richter Scale) have occurred on or near INL. Areas adjacent to the Snake River Plain have a fairly high rate of seismic activity with a 7.3 magnitude earthquake occurring to the northwest of INL in 1983. However, no damage occurred at INL (DOE 2000). Although volcanic zones have been identified at INL, eruptions are not likely. INL has a moderately low seismic risk (DOE 2002b).

Soils: Soils at INL are derived from volcanic and sedimentary rocks. The land is composed of basalt lava flows, Rhyolitic (granite-like) volcanic rocks and poorly consolidated sediments of silts, sands, gravels, and clays deposited by wind, streams, or in lakes. There are no prime farmlands within INL (DOE 2005a).

3.2.6 Biological Resources

A cool, desert ecosystem and shrub-steppe plant communities characterize the INL complex. Ninety eight percent of the land is relatively undisturbed and provides habitats for many animal species native to the region. Numerous plant species and plant communities are present at INL with sagebrush being the major community. The sagebrush community, critical winter/spring range for sage grouse and pronghorn populations, and the juniper community, used as raptor and songbird nesting areas, are considered sensitive habitats. Peripheral areas of INL are used as sheep and cattle grazing areas. The INL Sagebrush Steppe Ecosystem Reserve occupies about 29,950 ha (74,000 ac) of land in the north central portion of the complex and provides habitats for numerous rare and sensitive species (DOE 2000).

INL supports numerous animal species, including two amphibian, 11 reptile, 225 bird, 44 mammal, and a variety of migratory birds. Animals commonly found at INL include the short-horned lizard, gopher snake, sage sparrow, Townsend's ground squirrel, and black-tailed jackrabbit with raptor-species and carnivores such as coyote and mountain lion. Game animals at INL include sage grouse, mule deer, elk, and pronghorn. Aquatic life is present in the streams and ponds at INL including six species of fish (DOE 2005a).

Threatened or Endangered Species: Two Federally listed threatened species, the bald eagle (*Haliaeetus leucocephalus*) and the gray wolf (*Canis lupus*), and a candidate plant species, inconspicuous phacelia (*Phacelia inconspicua*), could possibly be found on INL. An additional ten other plant, reptile, bird, or mammal species that are Federal species of special concern could live on INL (FWS 2004). The U.S. Fish and Wildlife Service recently proposed to de-list the gray wolf from the threatened and endangered list (69 FR 10956). The state of Idaho has classified a total of seven plant species and one bird species (bald eagle) as threatened, state priority, state sensitive, or state monitor that could possibly occur at INL. No threatened or endangered critical habitats occur at INL. The DOE is assessing impacts on threatened and endangered species from a wildfire in July 2000 that burned an extensive area of southwestern INL (DOE 2005a).

3.2.7 Socioeconomics

The INL employs over 8,000 research, professional, administration, and support personnel. Over 95 percent of the workforce lives in a seven-county regional economic area: Bannock, Bingham, Bonneville, Butte, Clerk, Jefferson, and Madison, which represent over seven percent of employment in the regional economic area. INL is the second largest employer in Idaho and expends over \$1 billion (about 0.01 percent of Idaho's Gross State Product (GSP)) annually to the local and Idaho economy by way of direct and indirect provision of wages, salaries, purchase, education, development grants, goods, and services. INL is directly or indirectly responsible for the employment of over 18,000 people in Idaho (DOE 2002b; INEEL 2001).

In 2000, population in the regional economic area was 258,774 persons, an increase of about 18 percent from 1990 (DOE 2002b). During the same period, Idaho population increased 28.5 percent, to 1,293,953 persons (USCB 2004).

3.2.8 Cultural Resources

The INL complex contains a large number of prehistoric and historic archeological sites, fossils, military and Cold War era structures and features, and sites important to Native American groups. Numerous buildings and structures are listed or potentially eligible for listing in the NRHP. The Experimental Breeder Reactor Number 1, an NRHP listed property and also a National Historic Landmark, was used in the demonstration of use of nuclear fission to produce usable electricity. The land at INL is culturally important to Native American Groups because of its association with the Shoshone and Bannock Tribes (DOE 2005a).

3.2.9 Hazardous and Radioactive Waste

Waste management at INL is accomplished by using appropriate treatment, storage, and disposal technologies, and in compliance with all applicable Federal and State statutes and DOE Orders. In 2004, INL managed 21 m³ (741 ft³) of transuranic and mixed transuranic waste; 82,354 m³ (2,907,919 ft³) of low-level radioactive waste; 23,907 m³ (844,156 ft³) of mixed low-level radioactive waste; 927 m³ (32,732 ft³) of hazardous waste; 2,000,000 m³ (70,620,000 ft³) of non-hazardous liquid waste; and 49,430 m³ (1,745,373 ft³) of non-hazardous solid waste. During 2004, included in the inventory were 11,140 m³ (393,353 ft³) of transuranic, mixed transuranic, and alpha low-level radioactive wastes; 2,115 m³ (74,680 ft³) of low-level radioactive wastes; and 5,909 m³ (208,646 ft³) of mixed low-level radioactive wastes (DOE 2005a).

Past waste disposal methods at INL have resulted in localized plumes of radiochemical and other chemical constituents in the aquifer. Of concern are tritium and strontium-90 plumes. Changes from previous waste disposal methods have resulted in containment of these plumes. Tritium concentrations have decreased and strontium-90 concentrations have remained the same (DOE 2000). Testing of offsite drinking water samples has yielded tritium levels above the minimum detectable concentration. However, the highest concentration of tritium was well below the EPA's allowable contaminant level. Tritium was not detected in offsite surface water samples (DOE 2002b). In 1989, INL was declared a Superfund Site (Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, (42 U.S.C. 9601 *et seq.*), (CERCLA)), and was placed in the National Priority List (NPL). Monitoring and cleanup actions are ongoing (EPA 2004b).

3.2.10 Transportation of Radioisotope Components

Packaging: DOE has established requirements and guidelines that comply with DOT regulations for transporting radioisotopes as well as encapsulation of radioisotopes and associated hardware for transportation. The Pu-238 transportation containers consist of a cask/cage assembly, an aluminum thermal shield, heat dissipating system, and stainless steel primary and secondary containment vessels. These vessels are designed to withstand all pressure buildups that could occur during normal conditions of transport and hypothetical accident conditions (DOE 2003a).

Transportation: DOE uses a Secure Transportation System to transport radioisotopes. These transport systems include tie-down equipment, temperature monitoring, fire alarms, and access denial systems. The vehicles undergo extensive checks prior to each trip as well as periodic maintenance checks (DOE 2002b).

3.2.11 Human Health

The DOE has modeled non-radiological releases from MFC. Concentrations of any hazardous and toxic compounds would be well below regulatory levels. In 2003, approximately 7% (539 curies) of the total release of airborne radionuclides at INL was attributed to the MFC. Current regulations limit the dose resulting from releases of airborne radioactivity from DOE facilities to no more than 10 mrem per year to a member of the general public. In 2003, the maximally exposed offsite individual received a total of 0.035 mrem. The average individual worker dose at INL in 2003 was 56 mrem (DOE 2005a). For perspective, a modern chest x-ray results in a dose of about 6 mrem and about 65 mrem is received from a diagnostic pelvic and hip x-ray (DOE 2000).

3.3 SANDIA NATIONAL LABORATORY, ALBUQUERQUE, NEW MEXICO

The DOE has used the Sandia National Laboratory (SNL) previously to perform safety test activities associated with R&D efforts similar to those that may be required for the action addressed in this DPEIS. Although it has not been decided that safety testing would be required as part of the advanced RPS development, if such testing (with fuel simulant) were to occur, SNL might be considered for use for advanced RPS safety testing. SNL is addressed in the event such activities occur at SNL. The affected environment for SNL is described in detail in the Final Sandia National Laboratory Site-Wide Environmental Impact Statement (DOE 1999c) that bounds the activities at that facility supporting the Proposed Action of this DPEIS. NASA's summary of the affected environment for SNL is incorporated by reference and is limited to the Albuquerque site.

3.3.1 Land Resources

The SNL is located in Bernalillo County, New Mexico, southeast of Albuquerque and uses about 3,560 ha (8,800 ac) of land within Kirtland Air Force Base (KAFB). KAFB occupies about 20,860 ha (51,560 ac) of Bernalillo County and is bounded on the north by the City of Albuquerque, on the east by the Manzanita Mountains and Cibola National Forest, on the south by Pueblo of Isleta, and on the west by the Albuquerque International Airport and state land. The area surrounding KAFB is characterized by grasslands, woodlands, rocky slopes, riparian arroyo (water channel or gully) or canyon, and altered land. Land use at SNL fits into a category of industrial and research park uses with laboratories, test facilities, warehouses, and administrative buildings (DOE 1999c).

SNL is a multi-program lab, primarily performing national defense R&D, energy, and environment projects as well as providing engineering design for all non-nuclear components in the nation's nuclear weapons program (SNL 2004).

3.3.2 Air Resources

Climate: The climate in Bernalillo County and at KAFB can be characterized as semi-arid with annual precipitation ranging from about 19 to 25 cm (7.5 to 10 in) and annual temperature ranging from about 22 to 93° F (-6 to 34° C) (NMED 2004b). Most of the precipitation occurs from thunderstorms from July through September. Less than 5 cm (2 in) of precipitation occurs during the winter months with limited snowfall. Wind patterns occur with upslope flows during the day and down slope flows during the night (DOE 1999c).

Air Quality: Air quality is regulated through the NAAQS promulgated under the CAA. See Section 3.1.2 for additional discussion on primary and secondary air quality standards and criteria pollutants.

Air quality in New Mexico is controlled on a regional basis and parameters such as climate, meteorology, topography, vegetation, land use, population, and growth projections are considered when setting air quality control regions. SNL/KAFB is in the Albuquerque-Mid Rio Grande Intrastate Air Quality Control Region and this region includes all of Bernalillo County and portions of Sandoval and Valencia Counties (NMED 2004b). Air quality within this region is classified as in attainment or unclassifiable with respect to the NAAQS except for CO, which is classified as maintenance (DOE 1999c).

3.3.3 Water Resources

In general, KAFB withdraws about 4.4 billion l (1.16 billion gal) of water per year (in 1996) from the Albuquerque-Belen Basin aquifer (DOE 1999c).

Surface Water: Surface water at KAFB occurs as intermittent streams fed by springs or during summer thunderstorms and generally flows westwards along numerous drainage courses. Some surface flow may be lost by evaporation or infiltration. Summer thunderstorms could result in local flood conditions and surface runoff. Snowmelt in the Manzanita Mountains could also produce local surface runoff. Wetlands occur at several springs with a total area of less than 0.4 ha (1 ac) (DOE 1999c).

Water discharge from SNL properties occurs as surface runoff from storm events. Runoff water is collected in storm sewers and is discharged under NPDES permits. Effluent discharges occur under a NPDES permit with a yearly discharge of about 1,064 million l (281 million gal) (DOE 1999c).

Groundwater: Groundwater occurs in the Albuquerque-Belen Basin aquifer on the western portion of KAFB and in limited quantities in the fractured bedrock, *i.e.*, the bedrock aquifer, on the eastern portion of KAFB. The Albuquerque-Belen Basin aquifer lies about 150 m (500 ft) below the surface and serves as the source of municipal water for Albuquerque. The depth to groundwater in the bedrock aquifer could vary from near the surface at arroyos to about 46 m (150 ft) below the surface with flow generally towards the west. A transition zone exists between the eastern and the western aquifers where the groundwater depth could vary from near the surface to about 150 m (500 ft) below the surface. Excess groundwater withdrawal over

recharge is of concern. Recharge occurs during short-term storm events from infiltration of arroyo water (DOE 1999c).

3.3.4 Ambient Noise

Activities at the KAFB, the international airport, and SNL contribute to ambient noise in the region. SNL noise activities include test programs, high explosive tests, tests of rocket motors, large-caliber weapons testing, tests producing sonic booms, and industrial and construction activities. Outside KAFB, impulse noise is typically heard as dull thuds or short bursts lasting less than three seconds. In general, background noise produced by SNL would be in the range of 50 to 70 dBA (DOE 1999c).

3.3.5 Geology and Soils

Geology: Unconsolidated geologic material, and fractured and porous bedrock underlies KAFB. Regional geologic features include mountains, arroyos, and canyons. The western portion of KAFB lies on the Albuquerque-Belen Basin and consists of unconsolidated sedimentary fill of gravels, sands, silts, and clays, collectively called the Santa Fe Group. The eastern portion of KAFB consists of bedrock and alluvial material. A transition region exists between the eastern and the western portions of KAFB and consists of unconsolidated sedimentary fill and bedrock. The West Sandia Fault, Sandia Fault, Tijeras Fault, Manzano Fault, and Hubbell Springs Fault lie within this transition region, generally on a north-northeast orientation. In addition, the Coyote Fault lies on the eastern portion of KAFB on a north-south orientation. These faults have not shown movement within the last 10,000 years. In 1971, an earthquake of magnitude 4.7 (Richter Scale) occurred in the Albuquerque area, the largest recorded. No appreciable damage was noted to SNL buildings (DOE 1999c).

Soils: Eroded bedrock in the Manzanita Mountains to the east of KAFB and subsequent down slope transportation by water has contributed to the soils at SNL. These soils have high naturally occurring concentrations of arsenic, beryllium, and manganese metals, which are constituents of the bedrock. Soil contamination at SNL has occurred as a result of past activities such as explosions, destruction, or burning of tested devices containing hazardous material. Contaminants of concern include depleted uranium, lead metal, and tritium. SNL has cleanup and remediation programs to address such sites (DOE 1999c).

3.3.6 Biological Resources

Animal habitats include cliff faces, caves, abandoned mines, drainages, grasslands, woodlands, riparian (occurring near bodies of water), and altered land. Animals commonly found include black bear, mountain lion, fox, mule deer, prairie dog, bats, reptiles, rodents, amphibians, and many resident and migratory birds (DOE 1999c).

Threatened or Endangered Species: No Federally listed threatened or endangered species occur at KAFB; however, the recently delisted American peregrine falcon (*Falco peregrinus anatum*) and the mountain plover (*Charadrius montanos*) could reside onsite (DOE 1999c). Seventeen bird, mammal, reptile, or plant species found at KAFB are listed as Federal species of concern or sensitive species (FWS 2004). The state of New Mexico has listed a total of 11 bird, mammal, or plant species found at KAFB as threatened, sensitive, or rare. Ecological resources at KAFB are managed in accordance with the U.S. Air Force directives and guidelines (DOE 1999c).

3.3.7 Socioeconomics

SNL employs over 7,000 scientists, engineers, technologists, and administrative staff (SNL 2004). Over 97 percent of these employees live in the City of Albuquerque in Bernalillo County. SNL is responsible for about \$4.4 billion or about 9 percent of the economic activity (in FY 1998) in the region, which encompasses the counties of Bernalillo, Sandoval, Valencia, and Tarrant, by way of wages, salaries, and purchase of goods and services. SNL is directly or indirectly responsible for the employment of over 27,500 people representing 7.5 percent of total employment in this region (Lansford, et. al., 1999).

In 2000, the population in Bernalillo, Sandoval, Valencia, and Tarrant counties was 729,649 persons, an increase of about 21.7 percent from 1990. During the same period, New Mexico population increased by about 20 percent, to 1,819,046 persons (USCB 2004; DOE 1999c).

3.3.8 Cultural Resources

A large number of prehistoric Native American campsites, historic archeological sites such as mining, agriculture, and ranching sites, and architectural properties are present within KAFB. Some of these sites are recommended as eligible or potentially eligible for listing in the NRHP; consultations with the SHPO are ongoing. No traditional cultural properties (*e.g.*, sites important to Native American tribes) are presently identified at KAFB. However, consultations with Native American tribes are ongoing and such sites may be identified in the future (DOE 1999c).

3.3.9 Hazardous and Radioactive Waste

Several types of hazardous and radioactive wastes are generated from SNL activities. Radioactive wastes include low-level waste, low-level mixed waste, transuranic (TRU) waste, and mixed TRU waste. Hazardous wastes include chemical, explosive, medical, asbestos, and polychlorinated biphenyl (PCB) wastes. The wastes are stored at SNL and some mixed wastes (radioactive waste) are treated onsite. In addition to the yearly waste generated from SNL operations, SNL has also stored about 768 m³ (27,121 ft³) of low-level waste, 103 m³ (3,637 ft³) of low-level mixed waste, and 18 m³ (636 ft³) of TRU and mixed TRU waste that are pending disposal, which are referred to as legacy waste. The inventory of legacy waste at SNL is expected to be zero in 2005. Hazardous wastes at SNL are shipped offsite for disposal (DOE 1999c).

Past waste management activities and pollutants from environmental restoration sites, the Liquid Waste Disposal Site, the Lurance Canyon Burn Site, and the Chemical Waste Landfill have contributed to groundwater contamination at SNL. Contaminants such as trichloroethene, nitrates, and petroleum hydrocarbons such as toluene, ethylbenzene, and xylenes, have been detected in the aquifers with trichloroethene and nitrates measuring above regulatory levels. Other pollutants of concern include uranium, thorium, TRUs, fission products, tritium, and hexavalent chromium (DOE 1999c). Cleanup of contaminated sites is ongoing (DOE 2005a).

3.3.10 Transportation of Radioisotope Components

Packaging: DOE has established requirements and guidelines that comply with DOT regulations for transporting radioisotopes as well as encapsulation of radioisotopes and associated hardware for transportation. The Pu-238 transportation containers consist of a cask/cage assembly, an aluminum thermal shield, heat dissipating system, and stainless steel primary and secondary

containment vessels. These vessels are designed to withstand all pressure buildups that could occur during normal conditions of transport and hypothetical accident conditions (DOE 2003a).

Transportation: DOE uses a Secure Transportation System to transport radioisotopes. These transport systems include tie-down equipment, temperature monitoring, fire alarms, and access denial systems. The vehicles undergo extensive checks prior to each trip as well as periodic maintenance checks (DOE 2002b).

3.3.11 Human Health

Current regulations limit the dose resulting from releases of airborne radioactivity from DOE facilities to no more than 10 mrem per year to a member of the general public (DOE 2002b; DOE 2000). For perspective, a modern chest x-ray results in a dose of about 6 mrem and about 65 mrem is received from a diagnostic pelvic and hip x-ray (DOE 2000).

At SNL, workers and members of the general public receive approximately the same background radiation dose with the exception of some workers who receive an additional dose from working in specific radiation facilities. Using local population distribution within 80 km (50 mi) of SNL where approximately 732,823 persons lived (in 1996), the collective population dose from SNL operations for 1996 was 0.14 person-rem for these individuals (DOE 1999c).

3.4 ABERDEEN PROVING GROUND, ABERDEEN, MARYLAND

The Aberdeen Proving Ground (APG) is a U.S Army facility. The DOE has used APG previously to perform safety test activities associated with R&D efforts similar to those that may be required for the action addressed in this DPEIS. Although it has not been decided that safety testing would be required as part of the advanced RPS development, if such testing (with fuel simulant) were to occur, APG might be considered as a location for such testing. APG is addressed in the event such activities occur at APG. The affected environment for APG is described in detail in the Integrated Natural Resources Management Plan (DOD 2001b) that bounds the activities at that facility supporting the Proposed Action of this DPEIS. NASA's summary of the affected environment for APG is incorporated by reference.

3.4.1 Land Resources

The APG is mostly located in Harford County, Maryland with less than two percent in eastern Baltimore County, and is about 32 km (20 mi) northeast of the City of Baltimore. APG is bounded on the east and the south by the Chesapeake Bay, on the west by the towns of Edgewood and Aberdeen, and on the north by Swan Creek. The majority of land on APG is undeveloped. The western boundary of APG abuts urban, residential, commercial, industrial, and institutional areas, including the City of Aberdeen, which lies at the northwestern boundary of APG (DOD 2001a; DOD 2001b).

The APG is about 29,000 ha (72,000 ac) in extent including offshore areas of the Chesapeake Bay. About 90 percent of APG is designated as a test range and supports three main areas of defense: R&D and acquisition; emergency preparedness and response; and safe, secure chemical weapons storage, remediation, and demilitarization. In addition, APG supports development and testing of military materials, and training officers and enlisted personnel in the use and maintenance of munitions (DOD 2001b).

3.4.2 Air Resources

Climate: Continental and maritime air masses influence the climate at APG. The Atlantic Ocean and the Chesapeake Bay produces moderating effects in the area with warmer, milder winters than experienced by areas further west. The average annual temperature is 55° F (12.7° C) with an average high of 76.8° F (24.8° C) in July and low of 32.6° F (0.3° C) in January. The average annual rainfall is 105.4 cm (41.49 in) with the highest rainfall occurring in August and lowest in January. Prevailing winds are from west to northwest with average wind speeds of about 16 km/hr (10 mph). The area could experience thunderstorms, hurricanes, and winter storms with wind speeds of 80 km/hr (50 mph) or more (DOD 2001b).

Air Quality: Air quality is regulated through the NAAQS promulgated under the CAA. See Section 3.1.2 for additional discussion on primary and secondary air quality standards and criteria pollutants.

The Maryland Department of Environment measures criteria pollutants in Harford and Baltimore Counties. These two counties are in attainment for all criteria pollutants except for PM_{2.5} and O₃ (EPA 2005; EPA 2004c). Concentrations of criteria pollutants are estimated for APG based on emissions from point sources. Results of such estimations show that existing APG activities cause minor effects on ambient concentrations of SO₂ and moderate effects on ambient concentrations of NO₂, CO, PM, and O₃. Release of global warming gasses and ozone depleting substances from APG activities are estimated to cause negligible impacts. Test firing of munitions at test ranges or natural causes could cause brush fires. Smoke generated from these could cause a local nuisance and some visibility impairments (DOD 2001b). APG has two Title V (air) Operating Permits (APG 2004).

3.4.3 Water Resources

The APG obtains water from two offsite surface water sources. The water treatment plants collectively have the capacity to provide 31 million l (8.2 million gal) of water per day. Groundwater wells at APG are used as a secondary source when needed. However, these wells are not used for potable purposes (DOD 2001b).

Surface Water: About half of APG's acreage consists of water that includes creeks, rivers, wetlands, nontidal and tidal swamps, tidal flats, nontidal marshes, wet meadows, shallow ponds, estuarine marshes, estuarine bays, and deep waters, some of which tend to be slightly brackish. Major water bodies of APG are the Chesapeake Bay, Bush River, Swan Creek, Romney Creek, and Gunpowder River. Surface water at APG drains via numerous creeks and rivers into the Chesapeake Bay. The estuarine ecosystem at APG is comprised of large areas of tidal water in the Bush and Gunpowder Rivers, and the upper Chesapeake Bay. The tidal shorelines at APG are rich in marshlands and serves as an important habitat for both aquatic and terrestrial plant and animal species. There are no major freshwater river systems on APG; most are large tidal creeks classified within the estuarine system (DOD 2001b).

Limited data on surface water quality exists for APG. Based on readily observable stream conditions, stream substrate composition, and plant community composition, most of the creeks and other water bodies at APG appear to be in good condition. Past activities at APG have affected surface water quality. Concentrations of organic contaminants have mostly been below applicable water quality criteria except at two locations. The concentration of many inorganic

chemicals in water draining APG and in some adjacent areas of the Chesapeake Bay and its tributary estuaries has been detected above applicable water quality criteria. The concentration of inorganic chemicals above applicable criteria has also been detected in other waterways in the vicinity of APG. Waterways draining from APG are affected by runoff occurring elsewhere in Harford County (DOD 2001b).

Storm water runoff at APG occurs towards creeks, rivers, or the Chesapeake Bay. Runoff is either naturally cleansed via series of ponds or occurs in small areas and is presumed sufficiently diluted to have negligible impact on water quality. Sanitary wastewater from APG, formally treated by a wastewater treatment facility at APG, would be directed to the City of Aberdeen wastewater treatment plant. Industrial effluent from APG are treated onsite (DOD 2001b).

Groundwater: The Patuxent Formation of the Potomac Group Coastal Plain Sediments is the principal water-bearing formation in the APG region, an important source for the Baltimore area. The Potomac Group also includes the Patapsco and Arundel formations. From surface to below, respectively, Patapsco, Arundel, and Patuxent formations occur, with the Arundel Formation acting as a confining layer. The Arundel Formation can yield small quantities of water for domestic use. The Patapsco Formation yields large quantities of water; however, it is in direct hydrological contact with the Chesapeake Bay, making brackish water intrusion a potential problem. The groundwater source at APG is or has been the Potomac Group (DOD 2001b).

Groundwater quality data has been collected at APG as a part of remediation of past hazardous waste sites. Contaminants of concern include trichloroethene, trichloroethane, benzene, chloroform, arsenic, vinyl chloride, tetrachloroethane, dichloroethane, tetrachloroethene, diisopropyl methylphosphonate, and carbon tetrachloride. Remediation efforts are ongoing (DOD 2001b).

3.4.4 Ambient Noise

Noise at APG is generated by testing of weapons, munitions, and vehicles; road construction and repair; aircraft flying operations; and movement of Army and civilian vehicles. The Army has prepared an Installation Compatible Use Zone (ICUZ) Program for land use that also addresses potential noise issues. The test ranges at APG are within the ICUZ Program designated noise areas. During certain periods of the day, sounds from ordnance testing can be heard at the boundary of APG (DOD 2001b).

3.4.5 Geology and Soils

Low hills, shallow valleys, and flat plains characterize the topography at APG with elevation ranging from sea level to about 18 m (60 ft) above sea level (DOD 2001b).

Geology: APG is within the Atlantic Coastal Plain Physiographic Province and is underlain first by unconsolidated sediments such as clay, silt, sand, and gravel to depths of about 213 m (700 ft) and then by crystalline rocks and rift-basin sedimentary rocks. Several regional faults exist; however, with the absence of large historical earthquakes, the seismic risk for the Chesapeake Bay region is low. Small earthquakes have occurred near APG with magnitudes of less than 3 (Richter Scale) (DOD 2001b).

Soils: Soils at APG are mainly loams and silt loams and have physically and chemically been affected by range activities and past operations. Physical effects on soils have been moderate as

test ranges occupy a large portion of the land area. Inland erosion at APG is moderate and restricted to areas that have little vegetative cover, high relief, and flowing water. Localized, moderate to severe shoreline erosion occurs due to natural causes along the Chesapeake Bay shoreline and windward shoreline areas. APG has undertaken projects to stabilize shoreline erosion. Small, localized areas, on the order of acres, have been chemically contaminated from past activities. APG has an ongoing program to cleanup such sites (DOD 2001b).

3.4.6 Biological Resources

APG lies on the Atlantic Plain Physiographic Province and has plant communities of mixed deciduous forests such as oak, sweet gum, beech, maple, poplar, cherry, and locust; wetlands; meadows; and developed areas. About 6,475 ha (16,000 ac) at APG are forested land and about 5,261 (13,000 ac) are wetlands. The forested lands vary in size and are fragmented by watercourses, wetlands, open fields, and roads. Limited commercial potential exists for the forested lands as most of these areas are contaminated by unexploded ordnances (UXO) and have restricted access (DOD 2001b).

Animals that inhabit APG include birds, amphibians, reptiles, mammals, and fishes. A survey of birds has listed 108 species that include common birds such as yellowthroat, bunting, towhee, gray catbird, and white-eyed vireo, including neotropical migrants, flycatchers, and waterfowl. Permanent and seasonal use of APG by birds is very high as APG is located in the upper Chesapeake Bay, which is a part of the Atlantic flyway for migratory birds. Amphibians and reptiles include species of frogs, turtles, and snakes. Mammal species include deer, beaver, muskrat, red fox, raccoon, mink, coyote, bats, shrew, and vole. Waters at APG provide breeding grounds, nurseries, and habitats for many fish species. Common fishes include bluegill, bullhead, carp, bass, perch, and catfish (DOD 2001b).

Threatened or Endangered Species: The Federally listed threatened or endangered bald eagle (*Haliaeetus leucocephalus*) and the shortnose sturgeon (*Acipenser brevirostrum*) can be found at APG. Three State listed bird species, the northern harrier (*Circus cyaneus*), the sedge wren (*Cistothorus plantensis*), and the black rail (*Laterallus iamaicensis*), with the respective designations, rare, threatened, and in need of conservation, can be found at APG. No Federally listed plant species occur at APG. However, two plant species are under review for Federal listing. A total of 50 State listed plant species with the designations of endangered, threatened, highly state rare, state rare, or on a watch list, occur at APG (DOD 2001a).

3.4.7 Socioeconomics

More than 7,500 civilians, 5,000 military personnel, and nearly 3,000 contractor and private business personnel work at APG. In addition, APG supports more than 16,000 military retirees and retiree family members. The majority of these persons live in Harford County. APG is the largest employer in Harford County and is one of the largest employers in the State of Maryland. APG expended nearly \$2.3 billion in FY 1999, which included installation payroll, contracts, and other installation costs. The total economic impact on Harford County was \$520.9 million for FY 1999 (APG 2004).

Population counts are provided only for Harford County where more than 98 percent of APG is located. Less than two percent of APG is in Baltimore County (DOD 2001a). In 2000, population in Harford County was 218,590 persons, an increase of 20 percent from 1990.

During the same period, Maryland population increased 10.8 percent, to 5,296,486 persons (USCB 2004).

3.4.8 Cultural Resources

APG has enormous archeological potential because of its natural setting on the Chesapeake Bay; however, only a fraction of the area has been surveyed for the existence of archeological resources. Many prehistoric and historic sites have been identified within the surveyed areas. Several facilities at APG have been identified as potentially eligible for listing on the NRHP. The NRHP listed facilities include the Presbury House, the Gunpowder Meeting House, the Pooles Island Lighthouse, and two sites located within the Lower Deer Creek Valley National Register Historic District, the Churchville Test Course/Tank Proving Ground and the Deer Creek Pumping Station. APG has a Cultural Resources Management Plan to address cultural resources management (DOD 2001b).

3.4.9 Hazardous and Radioactive Material

Hazardous wastes are generated at APG by weapons and equipment testing; equipment maintenance and use; and research, development, test, and evaluation operations. Such waste is managed in accordance with applicable Federal, State, and Local rules and regulations and U.S. Army programs for managing hazardous wastes. UXO occur at areas within the installation and locations in the Chesapeake Bay (DOD 2001b). Two areas at APG were designated Superfund Sites in 1989 and 1990 and were placed in the NPL (EPA 2004b). Cleanup efforts at these sites are ongoing (DOD 2001b).

3.5 GLENN RESEARCH CENTER AT LEWIS FIELD, CLEVELAND, OHIO

The Glenn Research Center (GRC) consists of two sites in Ohio, the Lewis Field in Cleveland and the Plum Brook Station in west central Erie County. In the context of this summary, GRC refers only to Lewis Field since it is anticipated the activities associated with the Proposed Action would occur at this location.

3.5.1 Land Resources

GRC is located in western Cuyahoga County, Ohio and is predominantly within the limits of the City of Brook Park, approximately 32 km (20 mi) southwest of downtown Cleveland. GRC borders the Cleveland Hopkins International Airport to the east and to the north and west is the Rocky River Reservation, a part of the Cleveland Metropolitan Park District. The southern boundary of GRC is adjacent to highly urbanized and developed residential, business districts, and industrial complexes (GRC 2005).

GRC encompasses approximately 148 ha (365 ac) of land and supports NASA's research, technology, and development programs in the areas of aero-propulsion, space flight systems, space propulsion, space science applications, and space power. Most of GRC is considered fully developed with offices, test facilities, and support facilities, with the exception of about 69 ha (171 ac) that are considered undeveloped. All structures at GRC must conform to Federal Aviation Administration restrictions due to proximity to the Cleveland Hopkins International Airport. The recreational park and the Rocky River Reservation next to GRC are considered a protected environment. There are no national or state parks in the immediate vicinity of GRC (GRC 2005).

3.5.2 Air Resources

Climate: The climate at GRC can be characterized as continental. Summers are warm and humid, with average temperatures of 21° C (70° F). Winters are relatively cold and cloudy, with an average temperature of -2° C (28° F). Precipitation averages 89 cm (35 in) per year. Prevailing winds are from the south to southwest (GRC 2005).

Air Quality: Air quality is regulated through the NAAQS promulgated under the CAA. See Section 3.1.2 for additional discussion on primary and secondary air quality standards and criteria pollutants.

The City of Cleveland performs air monitoring for Cuyahoga County for criteria pollutants, nitrogen oxide, total suspended particulates, and toxic air pollutants. Cuyahoga County is designated as an attainment area (GRC 2005) except for the PM_{2.5} standard (EPA 2005). GRC currently operates under a CAA Title V Operating Permit, which was issued in 2004 (GRC 2004b).

3.5.3 Water Resources

The City of Cleveland municipal water supply system provided about 1.35 billion l (0.35 billion gal) of water in FY 2001 to GRC. The majority of water is used for institutional purposes with the balance for research (GRC 2005).

Surface Water: Rocky River and its tributary, Abram Creek, are surface water features at GRC. The Rocky River flows northwards along the western edge of GRC, separating GRC from the Rocky River Reservation and discharges into Lake Erie. Abram Creek crosses GRC and discharges to the Rocky River. There is no commercial fishing in the Rocky River or its tributaries except for recreational fishing. Surface water runoff from GRC flows through the storm sewer system and natural swales to Abram Creek and Rocky River. Lake Erie, located 8 km (5 mi) to the north, is an important fresh water fishery and a recreational resource for boating and beaches. The Rocky River is not a designated wild or scenic river but is considered a wildlife refuge by the local jurisdictions. There are no national seashores in the vicinity of GRC (GRC 2005).

Floodplains at GRC occur at Abram Creek. Abram Creek fulfills the criteria for an area of special flood hazard (defined as an area of land that would be inundated by a flood having a one percent chance of occurring in any given year). No other mapped floodplains occur at GRC and no facilities are present in the 100-year floodplain. The 500-year floodplain for GRC has not been mapped. Wetlands at GRC have not been officially delineated however a study performed in 2002 identified four areas as probable wetlands; no activities currently occur in these areas (GRC 2005).

Wastewater at GRC is comprised of sanitary, storm water, non-contact and contact cooling, cooling tower blowdown, and miscellaneous process discharge. There are three wastewater collection systems at GRC: sanitary, storm water, and industrial. Sanitary discharges for the three quarters prior to July 2003 averaged about 353 million l (93 million gal). These discharges are required to meet the local general sewer use ordinance effluent limitations. Storm water discharges occur under a NPDES permit. Storm water monitoring has indicated occasional exceedances of chlorine and mercury. These findings have been reported to the Ohio EPA with no additional action occurring from the Ohio EPA. Although the Industrial Waste Sewer

receives some wastewater, it is mainly used as an oil spill control system and a surge area for cooling towers when they require emptying for maintenance (GRC 2005).

Groundwater: Groundwater occurs in two distinct lithologic zones, in the shale bedrock and in perched lenses in the overlying unconsolidated materials. These zones are approximately 15 to 76 cm (6 to 30 in) thick. The zones are thought to be isolated and not to contain significant amounts of groundwater (GRC 2005).

Groundwater in the unconsolidated zone is expected to discharge to Abram Creek and Rocky River. The groundwater zone within the bedrock is under artesian pressure due to the low hydraulic conductivity of the overlying soils. However, the recharge rate is estimated to be very slow and the shale bedrock has very low permeability. Indications are that the bedrock aquifer can be expected to yield no better than approximately 3.8 l (1 gal) per minute (GRC 2005).

There are permitted drinking water wells within 6 km (4 mi) of GRC and many individuals in the Rocky River Basin use groundwater for drinking. No aquifer at GRC has been designated as a sole or principal drinking water source. Groundwater flow from GRC is toward Abram Creek and Rocky River. Groundwater is not used for water supply at GRC. In addition, there is no evidence of groundwater contamination or any underground injection wells at GRC (GRC 2005).

3.5.4 Ambient Noise

The Cleveland Hopkins International Airport is the largest noise source in the general vicinity of GRC. Other noise sources include a factory, traffic noise from Interstate highways, and a large exhibition hall. Noise sources at GRC include research operations (*e.g.*, wind tunnels and engine test cells), transient noises, NASA aircraft, construction activities, and traffic noise. The general noise level at GRC is well below the average day/night sound level of the Cleveland Hopkins International Airport. Noise level at the GRC fence line are generally below 70 dBA, with much of this noise attributed to offsite sources (GRC 2005).

3.5.5 Geology and Soils

The area near GRC consists of gently rolling uplands. GRC is generally level due to extensive cut-and-fill operations that reclaimed the area from steep drainage swales. These drainage features were filled in with a variety of undifferentiated soils and gravels, construction debris, and industrial and domestic waste (GRC 2005).

Geology: The area surrounding GRC is located on the western flank of the undeformed portion of the Appalachian Basin. The basin contains a southeastward-thickening prism of sandstones, carbonates, shales, and salts that aggregate to a thickness of about 1,980 to 7,010 m (6,500 to 23,000 ft). Bedrock in the immediate vicinity of GRC is composed of the Cleveland Shale Member of the Ohio Shale. The probability of an earthquake causing structural damage is minimal. The Ohio Shale is fissile, however, and offers differential resistance to applied stresses depending upon the inclination to the direction of stratification (GRC 2005).

Soils: Soils in the vicinity of GRC generally have low to very low permeability and are classified as a silty clay loam, although they often grade to a clay loam glacial till. The natural soils and parent materials in many cases have been removed or covered with fill. There are no prime farmlands within GRC (GRC 2005).

Four polychlorinated biphenyl (PCB) transformer spills have been recorded since 1992. Three were small leaks of PCB oil or mineral oil with PCB's, and the fourth occurred from over-filling a transformer resulting in the loss of 132 l (35 gal) of mineral oil with PCB's. This site has been remediated (GRC 2005).

3.5.6 Biological Resources

GRC lies in the Beech-Maple Forest region of the great eastern Deciduous Forest of Eastern North America. This region has been classified as a mixture of Beech Forest, Mixed Oak Forest, Elm-Ash Swamp Forest, and Mixed Mesophytic Forest. Most of the site is now too highly disturbed to support significant numbers of indigenous Ohio plant species. The gorge of Abram Creek and the tops of the bluffs above the valley are the only areas that retain natural qualities (GRC 2005).

Animals that inhabit GRC include birds, amphibians, reptiles, butterflies and moths, and various mammals. Most common birds include the European starling, house sparrow, American robin, chimney swift, and house finch. Few amphibian species, one reptile, many species of butterflies and moths, and three common bat species have been identified at GRC. Other mammals, such as squirrels, chipmunks, rabbits, deer, and groundhogs, also likely inhabit the area (GRC 2005).

Threatened or Endangered Species: Two State listed potentially threatened plant species, pigeon grape (*Vitis cinerea*) and American chestnut (*Castanea dentata*), are found at GRC. GRC has no known adverse affects on endangered species beyond its borders (GRC 2005).

3.5.7 Socioeconomics

Over 3,113 scientists, engineers, administrative professionals, clerical staff, technicians, and trade personnel are employed at GRC, with over 65 percent of these employees living in Cuyahoga County (GRC 2005). The GRC total revenue was \$699 million (in FY 1998), with over 95 percent of the revenue derived from NASA. Other significant revenue sources were from other Federal agencies such as the National Oceanic and Atmospheric Administration, the Department of Defense, and the Department of Energy. Total economic impacts on the state of Ohio from GRC activities (FY 1998) resulted in \$1,155 million from direct, indirect, and induced spending; creation of 12,062 jobs (including GRC workforce), and \$384 million in direct, indirect, and induced earnings (Austrian and Wolf 2000).

In 2000, population in Cuyahoga County was 1,393,979 persons, a decrease of 1.3 percent from 1990. During the same period, Ohio population increased 4.7 percent, to 11,353,140 persons (USCB 2004).

3.5.8 Cultural Resources

Portions of GRC are considered very sensitive for potential archeological resources. Two GRC facilities (Rocket Engine Test Facility and Microgravity Research Laboratory) have been designated as National Historic Landmarks and the American Society of Mechanical Engineers considers an additional facility (Icing Research Tunnel) an International Historic Mechanical Engineering Landmark. In addition, the Central Area at GRC is eligible as a Historic District (GRC 2005).

3.5.9 Hazardous and Radioactive Materials

GRC uses hazardous materials for various institutional activities, which in turn generates hazardous wastes. Such waste is managed in accordance with applicable Federal, State, and Local rules and regulations and the GRC plan for managing hazardous and radioactive material. In 2002, GRC generated 83,515 kg (184,170 lb) and 275 m³ (9,712 ft³) of hazardous wastes. GRC uses ionizing radiation sources such as x-ray equipment and density gauges for various analytical and diagnostic uses. Users of such sources are trained professionals and uses of such equipment are strictly monitored following prescribed guidelines. While most ionizing sources are sealed sources, some uses are performed in unshielded facilities and outdoor locations. In such activities, exposure is controlled by maintaining appropriate radiation levels at a safe distance from the source and limiting access to the area with barriers and warning signs (GRC 2005).

3.6 JET PROPULSION LABORATORY, PASADENA, CALIFORNIA

The Jet Propulsion Laboratory (JPL) is managed by the California Institute of Technology in support of NASA. JPL's primary mission is the planning, advocacy, and execution of unmanned exploratory scientific flight through the solar system (JPL 2002). The JPL facilities include the main site at Pasadena, California and several other sites located elsewhere, such as the Deep Space Network Complexes, astronomical observatory at Table Mountain in California, and launch operation site at Cape Canaveral, Florida (JPL 2004a). This summary of the affected environment is for the main site at Pasadena as it is anticipated the activities associated with the Proposed Action would occur at this location.

3.6.1 Land Resources

The JPL facility is located in northwestern Pasadena in Los Angeles County, California and encompasses a total of 71 ha (176 ac). To the north are the San Gabriel Mountains and Angeles National Forest, to the east is the Arroyo Seco Canyon, to the south is the Los Angeles Metropolis, and to the west is the city of La Canada-Flintridge. Vegetation at JPL is characterized by native chaparral (shrubs and low trees adapted to dry conditions), coastal scrub, oak woodlands, grasses and forbs (non-woody plants that are not grasses), and landscaped plants. Land use at JPL resembles a university campus by appearance with offices and laboratory facilities for R&D work (JPL 2002).

3.6.2 Air Resources

Climate: The regional climate can be characterized as Mediterranean with warm, dry summers and mild, rainy winters. Approximately 80 percent of the annual precipitation, about 38.1 cm (15 in), occurs from November through April and annual temperature could range from about 32.5 to 95.5° F (2.7 to 35.2° C). In general, winds are mild throughout the year with daytime winds from the ocean and nighttime winds from land. Storms can occur in autumn from the Santa Ana winds (JPL 2002).

Air Quality: Air quality is regulated through the NAAQS promulgated under the CAA. See Section 3.1.2 for additional discussion on primary and secondary air quality standards and criteria pollutants.

California is divided into air basins with respect to air quality control within the state. An air basin may encompass entire counties or portions of counties. The South Coast Air Basin (SCAB) encompasses portions of Los Angeles, Riverside, and San Bernardino counties and all of Orange County. The South Coast Air Quality Management District (SCAQMD) manages air quality in the SCAB (SCAQMD 2004).

With respect to the NAAQS, the SCAB is in compliance with only SO₂ and Pb, and is non-attainment for CO, NO₂, O₃, PM₁₀, and PM_{2.5} (EPA 2005; EPA 2004c; JPL 2002). California has also established state ambient air quality standards for the criteria pollutants and sulfates, hydrogen sulfide, vinyl chloride, and visibility reducing particles. With minor differences, the California standards for criteria pollutants are more stringent than the NAAQS and in some cases, the averaging time for the respective pollutant differs from the NAAQS averaging time. The SCAB is in attainment or unclassifiable for the state SO₂, Pb, NO₂, and sulfates and non-attainment for the CO, O₃, and PM₁₀ standards (CARB 2004). The air monitoring station nearest to JPL has measured concentrations of CO, O₃, NO₂, PM_{2.5}, total suspended particulates, and sulfate. The Federal 1- and 8-hr, and State 1-hr standards for O₃, and Federal and State annual average mean for PM_{2.5} were exceeded. Data for SO₂, PM₁₀, Pb, hydrogen sulfide, vinyl chloride, and visibility reducing particles were not available for this station (SCAQMD 2002).

The JPL facility operates under a CAA Title V permit and is permitted by the SCAQMD as a Regional Clean Air Incentives Market facility for oxides of nitrogen (NO_x) (JPL 2002).

3.6.3 Water Resources

Surface Water: In general, surface drainage at the JPL site is from the north to the south. Underground storm drain systems discharge surface waters to the Arroyo Seco Canyon, an intermittent stream dependent upon rainfall for natural flow, to the east of the facility. Storm water discharge and groundwater discharge from an artesian well to the storm water system occurs under the NPDES. Sanitary wastewater is the principal source of wastewater and is discharged to the county wastewater system. Source water from industrial processes and specialized uses are captured and disposed of offsite as hazardous waste. There are no wetlands, wildlife refuges, or wild and scenic rivers at JPL. JPL facilities are within proximity to the Devil's Gate Reservoir, which is used for flood control, located in the Arroyo Seco Canyon (JPL 2002).

Groundwater: Groundwater occurs in the unconsolidated alluvial sediments of the Raymond Basin aquifer, which is bounded on the north by the San Gabriel Mountains, the west by the San Rafael Hills, and the south by the Raymond Fault. JPL is located in the Monk Hill sub-basin of the Raymond Basin where groundwater occurs from depths ranging from 30 to 73 m (100 to 240 ft) below the surface. The Raymond Basin aquifer is the source of potable water for the local communities. Groundwater flow is from the northwest to the southeast, past JPL, where the supply wells are located. The City of Pasadena provides water to JPL and water is stored in tanks with a total capacity of 9.5 million l (2.5 million gal). Groundwater recharge is by rainfall and artificial means via several spreading basins operated by the City of Pasadena (JPL 2002).

3.6.4 Ambient Noise

Employee traffic during peak periods, backup electric generators, experimental tests, and operations and maintenance activities are sources of noise at JPL. In general, noise sources are

located indoors. Experimental tests are conducted in acoustically designed rooms and test cells, and electric generators are muffled to reduce noise impacts. Daytime background noise levels measured at the boundary ranged from 43 to 60 dBA (JPL 2002).

3.6.5 Geology and Soils

Geology: The San Gabriel Mountains, a major regional geologic feature, are of the Quaternary Pacoima Formation and are composed of quartz-and-feldspar sandstone that is alluvial in origin. The JPL facilities are located on the alluvial plains of the San Gabriel Mountains. The alluvial deposits extend about 72 m (236 ft) below ground level. The elevation at JPL ranges from about 140 to 328 m (458 to 1,075 ft) above mean sea level. Geologic features include steep mountainous terrain, narrow ridges, moderate slopes, and graded land for the JPL facilities (JPL 2002).

Numerous strike-slips and thrust faults occur in the Los Angeles region. JPL is in the vicinity of the Sierra Madre and the San Gabriel faults, both of which are classified as active. Two branches of the Sierra Madre fault occur to the west and to the east of JPL, the Mount Lukens thrust fault system and the south branch of the San Gabriel thrust fault, respectively, with others occurring along the south edge of the San Gabriel Mountains. In 1991, the Sierra Madre earthquake occurred which caused landslides in the San Gabriel Mountains and damage to structures in the foothill communities. A segment of the Sierra Madre fault called the JPL Bridge Fault lies within JPL, including several potential rupture zones that are present in the western half of the facilities. The risk of a damaging earthquake in the Los Angeles Basin is estimated at approximately five percent per year and building codes account for seismic risks (JPL 2002).

Soils: The soil underlying JPL is primarily fine sandy loam of the Hanford Series, extending 51 to 76 cm (20 to 30 in) below the surface. Similar subsoil underlies and extends to depths of about 2 m (6 ft) followed by a granitic basement. Soil contamination has occurred at JPL and compounds such as carbon tetrachloride, dichloroethene, trichloroethene, and Freon have been detected. Investigations have determined that exposure to soil is unlikely to cause short-term or long-term adverse health effects to employees or the public due to low levels of chemicals of concern, the depths of these chemicals, or infrequent or unlikely exposure (JPL 2002).

3.6.6 Biological Resources

Approximately 37 percent of land, primarily on slopes and canyons, is relatively undeveloped and is vegetated by chamise-white sage, chamise, sumac, California sage brush, mixed sage, black sage, oak woodland, firebreaks, native and exotic grasses and forbs, and landscaped plants. A variety of wildlife such as lizards, skink, snakes, western scrub jay, towhee, hawk, woodpecker, pigeons, wrens, mockingbird, raven, crow, dove, starling, rabbit, squirrel, rats, coyote, skunk, and mule deer are supported by these plant communities (JPL 2002).

Threatened or Endangered Species: No Federally-listed threatened or endangered species or California-designated rare or endangered species are known to occur at JPL. Surveys of the site have found no evidence of such species, including special-status plants.

On April 13, 2005, the U.S. FWS published a final rule (70 FR 19561) designating areas throughout southern California as critical habitat for the arroyo southwestern toad (*Bufo californicus*), a Federal endangered species and California species of special concern. Although

JPL is in an area thus designated, this species has not been detected during site surveys and based upon terrain and habitat requirements is unlikely to occur at the facility (JPL 2002). Two California Species of Special Concern, the Cooper's hawk (*Accipiter cooperii*) and sharp shinned hawk (*Accipiter striatus*), have been observed at JPL. Other Federally listed threatened or endangered species, or California listed endangered or species of special concern have the potential to occur at JPL; however, surveys have resulted in zero observations of those species (JPL 2002).

3.6.7 Socioeconomics

JPL employs about 5,500 professional, technical, administrative, and contractor personnel, the majority of whom live in Los Angeles County (JPL 2004a; JPL 2002). JPL has an annual budget of approximately \$1.4 billion and mostly supports NASA R&D projects. Non-NASA R&D projects have included projects for other Federal agencies (JPL 2003; JPL 2002).

In 2000, population in Los Angeles County was 9,519,338 persons, an increase of about 7.4 percent from 1990. During the same period, California population increased by about 13.6 percent, to 33,871,648 persons (USCB 2004).

3.6.8 Cultural Resources

There are no known or recorded archeological resources at JPL. Several prehistoric villages and cemetery complexes, and historic places and landmarks are present in the vicinity, but none are at the main Laboratory site. The Space Flight Operations Facility and the Space Simulator building at JPL are listed in the NRHP (JPL 2002).

3.6.9 Hazardous and Radioactive Material

JPL uses hazardous materials for various institutional activities, which in turn generates hazardous wastes. Such waste is managed in accordance with applicable Federal, State, and Local rules and regulations and the JPL plan for managing hazardous and radioactive material. In 2003, JPL generated 22,000 kg (49,000 lb) of hazardous wastes, which were shipped offsite for disposal (JPL 2004b). JPL uses ionizing radiation sources for varying uses including equipment calibration and tracer experiments. Users of such sources are strictly monitored following prescribed guidelines. All radioactive wastes are sealed sources and are disposed offsite by a licensed contractor (JPL 2002).

Past wastewater disposal methods within the JPL site may have contributed to groundwater contamination. Compounds detected in onsite and offsite wells include volatile organics (*e.g.*, carbon tetrachloride, chlorobenzene, dichloroethane, dichloroethene, Freon®, trichloroethene, tetrachloroethene, toluene, total trihalomethanes, and xylene), perchlorate, and metals (*e.g.*, Pb, arsenic, total and hexavalent chromium). Carbon tetrachloride, trichloroethene, dichloroethane, perchlorate, and total chromium have measured above regulatory levels. In 1992, JPL was declared a Superfund Site and was placed on the NPL (EPA 2004b). Cleanup investigations and monitoring actions are ongoing (JPL 2002).

3.7 COMMERCIAL FACILITIES

The development, testing, and verification of the power conversion system for the MMRTG would occur at two commercial facilities: Pratt & Whitney Rocketdyne, Canoga Park, California and Teledyne Energy Systems, Hunt Valley, Maryland. The development, testing, and

verification of the power conversion system for the SRG would occur at three commercial facilities: Infinia Corporation, Kennewick, Washington; Lockheed Martin Space Systems Company, King of Prussia, Pennsylvania; Lockheed Martin Commercial Space Systems, Newtown, Pennsylvania; and at GRC.

The affected environment at the commercial facilities is not addressed in detail in this DPEIS. The development, testing, and verification of the power conversion system at the commercial facilities would be construed as industrial activities and would fall within the normal realm of operations at these facilities. Each facility involved in the MMRTG and SRG effort would use established procedures, processes, and existing resources if the Proposed Action were implemented. No new construction of buildings or additions to existing buildings would be needed however minor interior modifications may be undertaken.

In implementing the Proposed Action, these facilities would have to comply with applicable Federal, state, and local rules, regulations, and ordinances to meet with the requirements, standards, and guidelines; for example, air emissions, effluent discharges, solid and hazardous waste disposal, and noise abatement. Process products such as air emissions, effluents, and waste generation are not expected to require new or additional permitting or licensing and would be disposed of accordingly. Required permits are currently in place at these facilities to support the advanced RPS effort (NASA 2003).

4 ENVIRONMENTAL CONSEQUENCES

Two alternatives are addressed in this Draft Programmatic Environmental Impact Statement (DPEIS): the Proposed Action to develop two types of advanced Radioisotope Power System (RPS) and the No Action Alternative. This chapter describes the environmental impacts of the Proposed Action and the No Action Alternative. Under the Proposed Action, the National Aeronautics and Space Administration (NASA), in cooperation with the United States of America (U.S.) Department of Energy (DOE), would develop the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and the Stirling Radioisotope Generator (SRG) and continue its research and development (R&D) of alternative radioisotope power systems and power converter technologies. Under the No Action Alternative, NASA would not develop either advanced RPS (MMRTG and SRG). NASA would, however, continue to consider for future missions the use of available RPSs, such as the General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG), and would continue R&D efforts for alternative radioisotope power systems and power converter technologies.

The NASA R&D efforts involving alternative radioisotope power systems and power converter technologies are on-going activities and are addressed under both the Proposed Action and the No Action Alternative as these efforts will continue independent of the decision to be made in this EIS. If this research leads to the development of a new type of RPS, flight qualification of such systems with radioisotope fuel will be the subject of additional NASA NEPA documentation. The R&D effort on power conversion technologies have applicability to both radioisotope and non-radioisotope power systems. In addition, NASA will continue to evaluate power systems developed independently by other organizations for their viability in space-based applications.

4.1 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The principal near and mid-term activities of environmental interest associated with the Proposed Action include:

- Development of MMRTG technology, including:
 - R&D on specific MMRTG power converter concepts,
 - Testing of prototype MMRTG power converters prior to fueling to determine their characteristics, and
 - Testing of a fueled Qualification Unit to requirements more severe than expected during a mission.
- Development of SRG technology, including:
 - R&D of specific SRG power converter concepts,
 - Testing of prototype SRG power converters prior to fueling to determine their characteristics, and
 - Testing of a fueled Qualification Unit to requirements more severe than expected during a mission.
- Plutonium-238 fueled clad production for General Purpose Heat Source (GPHS) modules at Los Alamos National Laboratory (LANL).
- RPS operations at Idaho National Laboratory (INL), including:
 - Producing GPHS modules, and
 - Mating the fueled modules with advanced converters.

- Potential advanced RPS safety testing activities including impact testing of RPS with low activity level fuel simulants instead of plutonium-238.
- Long-term R&D efforts involving alternative radioisotope power systems and power converter technologies (see Section 4.3).

Environmental impacts of the activities at DOE facilities involved in the R&D efforts (including DOE-contracted commercial facilities) have been previously documented in DOE National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 *et seq.*), related documents and are briefly discussed here. Specific DOE NEPA documentation and other relevant existing documentation includes:

- The *Draft Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to the Production of Radioisotope Power Systems* (DOE 2005a),
- The *Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication* (DOE 1991),
- The *Environmental Assessment of the Import of Russian Plutonium-238* (DOE 1993a),
- The *Environmental Assessment of the General-Purpose Heat Source Safety Verification Testing* (DOE 1995),
- The *Site-Wide Environmental Impact Statement for the Continued Operation of the Los Alamos National Laboratory* (DOE 1999a),
- The *Programmatic Environmental Impact Statement for Accomplishing the Isotope Production Missions in the United States, including the Role of the Fast Flux Test Facility* (DOE 2000),
- The *Environmental Assessment for the Future Location of Heat Source/Radioisotope Power System Assembly and Operations Currently Located at the Mound Site* (DOE 2002b),
- The *Categorical Exclusions for MMRTG and SRG Research and Development Activities* (NASA 2004c), and
- Environmental Data and Analysis Information for MMRTG (DOE 2005b).

Each of the above-listed documents contains information and environmental impact analyses of ongoing, previously performed, or planned activities at DOE or other sites required to support the advanced RPS development. Information in the above-listed documents are incorporated by reference into this DPEIS and are summarized below. The integrated summary discussion of environmental impacts for anticipated activities at DOE sites that is presented in this DPEIS is based upon information in the above-listed documents and their associated Record of Decision (ROD) or Finding of No Significant Impact (FONSI).

If the proposed MMRTG and SRG development efforts are successful, then potential environmental impacts associated with the deployment of MMRTG and SRG to power space and planetary exploration missions would be anticipated. Environmental impacts associated with the production and testing of qualification units and the production, testing, and shipment of flight-ready units have been assessed in the existing DOE NEPA documentation identified above.

Specific future missions employing any of the technologies addressed in the Proposed Action would occur only if the proposed development effort is successful. The potential environmental impacts (including the potential consequences of launch accidents) associated with such future missions would be addressed in separate mission-specific NEPA documentation.

The following sections discuss the types of activities associated with the Proposed Action and their potential environmental impacts.

4.1.1 Environmental Impacts of Research, Development and Production of MMRTGs

The development of the MMRTG involves the production of a limited number of components, electrically heated units, and a single qualification unit for use during radioisotope fueled qualification testing (impacts associated with the fueling and operation of the qualification unit are addressed in subsequent sections). The design, fabrication, and testing of the MMRTG converter components would be performed at commercial installations. Principal locations associated with MMRTG development activities would include Pratt & Whitney (formerly Boeing) Rocketdyne (Canoga Park, California) and Teledyne Energy Systems (Hunt Valley, Maryland). Activities are expected to be performed at existing facilities and are expected to be similar in effect to on-going activities at such facilities. Modifications to the existing facilities and infrastructure needed to support research, development, test, and production activities would be expected to be minimal and are not expected to result in environmental impacts (DOE 2005b).

All facilities involved in the design, manufacture, and test of advanced RPS converter systems are subject to Federal environmental regulations and those of the respective states and localities in which the facilities are located. These include, but are not limited to, implementing regulations for the Clean Air Act (CAA), the Clean Water Act (CWA), and the Resource Conservation and Recovery Act (RCRA).

The minor environmental impacts associated with development of the MMRTG converters are expected to be within the permitted quantities of airborne emissions, waterborne effluents, and waste disposal at each of the involved facilities; and subsequently both the short-term and long-term environmental impacts are expected to be within the limits of all applicable environmental laws, permits, and licenses (NASA 2004c). Specifically:

- Any increases in air emissions as a result of MMRTG development would be expected to be minimal or non-existent and within existing permits.
- No direct adverse effects would be anticipated on either aquatic or terrestrial ecosystems as a result of MMRTG development as no major construction activities are anticipated.
- Impacts on water quality as a result of MMRTG development would be minimal and would be expected to be within the scope of referenced documents.

Project employment would be expected to consist primarily of current employees. Implementation of the development effort should result in no substantial change in the employment levels at the facilities and therefore, have little or no incremental socioeconomic impacts to the local communities.

Additional details are available in the following documentation:

- Environmental Data and Analysis Information for MMRTG (DOE 2005b)
- The *Categorical Exclusions for MMRTG and SRG Research and Development Activities* (NASA 2004c)

4.1.2 Environmental Impacts of Research, Development, and Production of SRGs

The development of the SRG involves the production of a limited number of components, electrically heated units, and a single qualification unit for use during radioisotope fueled qualification testing (impacts associated with the fueling and operation of the qualification unit are addressed in subsequent sections). The design, fabrication, and testing of the SRG converter components would be performed at both commercial and governmental installations. Principal locations associated with the SRG development activities include the Infinia Corporation (Kennewick, Washington), Lockheed Martin Space Systems Company (King of Prussia, Pennsylvania), Lockheed Martin Commercial Space Systems (Newtown, Pennsylvania) and the Glenn Research Center (GRC) (Cleveland, Ohio). Activities are expected to be performed at existing facilities and are expected to be similar in effect to on-going activities at such facilities. Modifications to the existing facilities and infrastructure needed to support research, development, test, and production activities would be expected to be minimal and are not expected to result in environmental impacts (NASA 2004c).

All facilities involved in the design, manufacture, and test of advanced RPS converter systems are subject to Federal environmental regulations and those of the respective States and localities in which the facilities are located. These include, but are not limited to, implementing regulations for the CAA, CWA, and RCRA.

The minor environmental impacts associated with development of the SRG converters are expected to be within the permitted quantities of airborne emissions, waterborne effluents, and waste disposal at each of the involved facilities; and subsequently both the short-term and long-term environmental impacts are expected to be within the limits of all applicable environmental laws, permits, and licenses (NASA 2004c). Specifically:

- Any increases in air emissions as a result of SRG development would be expected to be minimal or non-existent within existing permits.
- No direct adverse effects would be anticipated on either aquatic or terrestrial ecosystems as a result of SRG development as no major construction activities are anticipated.
- Impacts on water quality as a result of SRG development would be minimal and would be expected to be within the scope of referenced documents.

Implementation of the development effort should result in an increase in the employment levels at the Infinia Corporation facilities however the increase would have, little or no socioeconomic impacts to the local communities.

All NASA facilities, including GRC, maintain an Environmental Resources Document (ERD). These documents provide information on the existing environment for the NASA facility and address the impacts associated with all facility activities. The impacts associated with SRG research, development, and test activities at the GRC would not be expected to exceed the limits reported in its ERD and would be within the scope of normal operations at these facilities (GRC 2005).

Additional details are available in the following documentation:

- *The Categorical Exclusions for MMRTG and SRG Research and Development Activities* (NASA 2004c)
- *Environmental Resources Document* (GRC 2005)

4.1.3 Environmental Impacts of Plutonium-238 Transportation to LANL

Under the Proposed Action, plutonium would be needed for the Qualification Units for both the MMRTG and the SRG. Over the near term, DOE would continue exercising its option to purchase Russian plutonium-238 (if available) to meet the needs of future U.S. space exploration missions (DOE 2000).

Activities and impacts associated with transporting plutonium-238 to the U.S. from Russia are evaluated in two other NEPA documents: *Environmental Assessment of the Import of Russian Plutonium-238* (*Russian Plutonium-238 EA*) (DOE 1993a), and *Finding of No Significant Impact for Import of Russian Plutonium-238 Fuel* (DOE 1993b). The proposed action addressed in the Russian Plutonium-238 EA was to import up to 40 kilograms (kg) (88 pounds (lb)) of plutonium-238 fuel (isotopic mass) in powdered dioxide form from Russia to supplement the current U.S. inventory. The action includes the transportation by ship of Russian plutonium-238 in 5-kg (11-lb) increments from St. Petersburg, Russia, to a U.S. port of entry. DOE considered the environmental consequences on global commons (*i.e.*, portions of the ocean not within the territorial boundary of any nation) in accordance with Executive Order 12114 (44 *Federal Register* (FR) 1957). From the U.S. port of entry, the plutonium-238 is ground transported by DOE Safe Secure Trailer/Safe Guards Transport (SST/SGT) to LANL and is added to LANL's portion of the existing U.S. plutonium-238 inventory. The dose to transportation workers associated with importing 40 kg (88 lb) of plutonium-238 to LANL was reported to be 2.6 person-rem; the dose to the public was reported to be 4.5 person-rem. Accordingly, incident-free transportation of plutonium-238 would result in 0.0011 latent cancer fatalities among transportation workers and 0.0023 latent cancer fatalities in the total affected population over the duration of the transportation activities discussed in the Russian Plutonium-238 EA (DOE 1993a).

The reported transportation accident risks under this option in the Russian Plutonium-238 EA (DOE 1993a) for the importation of 40 kg (88 lb) of plutonium dioxide are as follows: a radiological dose to the population of 0.2 person-rem, resulting in 1.0×10^{-4} latent cancer fatalities; and traffic accidents resulting in 0.0032 traffic fatalities. These estimates include the risk to the crew, handlers, and the public during both ocean and highway transportation (DOE 1993a).

DOE would need to import less than 10 kg (22 lb) to fuel the Qualification Units in support of MMRTG and SRG development. Even with these amounts for the Qualification Units, the total amount imported would not exceed the 40 kg (88 lb) total planned by DOE. Therefore, the impacts associated with importation of plutonium-238 for the Proposed Action would be within the envelope of activity and impacts analyzed in DOE's Environmental Assessment (EA) of importation of Russian plutonium (DOE 1993a).

Over the longer term, DOE intends to reestablish its ability to produce plutonium-238 domestically. The environmental impacts of this option have been extensively evaluated and reported in the *Programmatic Environmental Impact Statement for Accomplishing the Isotope Production Missions in the United States, including the Role of the Fast Flux Test Facility* (DOE/EIS-0310, December 2000; Records of Decision January 26, 2001 [66 FR 7877] and Amended Record of Decision August 13, 2004 [69 FR 50180]) (DOE 2000). Under this option, plutonium-238 would be produced domestically by irradiation of neptunium-237 targets in

existing, operating reactors at the Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee and the Idaho National Laboratory (INL).

Currently, DOE is considering plans to consolidate operations at its INL facility for the domestic production of plutonium; the NEPA process for this action is on-going (DOE 2005a). Three alternatives are being evaluated by DOE for this purpose: the Consolidation Alternative (consolidate all RPS activities at INL); the Consolidation with Bridge Alternative (maintain *status quo* until INL facilities become operative); and the No Action Alternative (maintain *status quo*). NASA holds no stake in the decision ultimately taken by DOE related to its long-term production of plutonium-238. NASA's Proposed Action in this DPEIS is independent of the Consolidation EIS (DOE 2005a) alternative selected by the DOE.

Additional details are available in the following DOE NEPA documentation:

- The *Draft Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to the Production of Radioisotope Power Systems* (DOE 2005a)
- The *Site-Wide Environmental Impact Statement for the Continued Operation of the Los Alamos National Laboratory* (DOE 1999a)
- The *Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication* (DOE 1991)

4.1.4 Environmental Impacts of Plutonium-238 Fuel Clad Production at LANL

LANL has the capacity to process, evaluate, and test up to 25 kg (55 lb) of plutonium-238 per year (yr). Less than 10 kg (22 lb) of plutonium-238 would be required to fuel an MMRTG and an SRG Qualification Unit. This is well below the annual processing capacity of the LANL fuel fabrication facility. These activities would take place at the plutonium facility, Technical Area (TA)-55-4 (DOE 1999a).

The activities at LANL associated with the Proposed Action would be within the normal scope of operations at the facility. The impacts of these operations at LANL on the following areas have been addressed in DOE NEPA documents. No substantial impacts were determined by DOE for any of these areas.

- Land Use
- Radiological and Non-Radiological Air Quality
- Noise
- Water Resources
- Geology and Soils
- Ecological Resources
- Cultural Resources
- Socioeconomics
- Site Infrastructure
- Waste Management
- Human Health Consequences

Activities associated with the Proposed Action would occur at DOE sites, such as LANL, within existing DOE facilities that: 1) already support the NASA's RPS needs as well as other government agencies, and 2) are subject to existing DOE NEPA documentation which addresses

production levels sufficient to include the production of plutonium-238 for NASA. The proposed advanced RPS development actions that would be performed at DOE facilities are the same as ongoing RPS activities; activities that would be expected to continue whether or not the development of the advanced RPS designs continue.

The Draft Consolidation EIS (DOE 2005a) has most recently analyzed the impacts associated with the above activities. This EIS addressed, among others, the impacts of activities associated with domestic production of plutonium-238 (from target fabrication through target irradiation in a nuclear reactor to the extraction of plutonium-238 from the targets), purification and encapsulation of the plutonium into fueled clads, and the assembly and testing of RPS units.

The Draft Consolidation EIS (DOE 2005a) reported that the impacts of continued national security and space related plutonium-238 fuel pellet fabrication operations at LANL (the No Action Alternative) would result in very, very small releases (on the order of 1×10^{-8} curies per year) with an estimated 1.8×10^{-5} person-rem/yr (or 3.8×10^{-7} Latent Cancer Fatalities over the 35 year operating life) and the maximally exposed member of the public dose of 1×10^{-9} rem/yr. The radiological impacts to the public from normal RPS related operations at the LANL facilities are well below any regulatory limit applicable to the DOE and are expected to be a very small fraction of the public health impact from sitewide operations. Worker exposures from continued operations were estimated as 19 person-rem/yr with an average worker dose of 0.24 rem/yr. These exposure estimates are within the limits set for occupational exposure and are not significantly different from worker exposures from other site plutonium glovebox activities.

The Draft Consolidation EIS (DOE 2005a) also reported that the radiological accident risks of continued national security and space related plutonium-238 fuel pellet fabrication operations at LANL would be very small (with a maximum annual cancer risk of 0.00025 for the surrounding population). Radiological risks to the public associated with potential accidental releases from RPS related activities also are a small contributor to the overall risks associated with operations at the site. Exposures from some accidents could be in excess of occupational dose limits for some site workers.

Continued national security and space related plutonium-238 fuel pellet fabrication operations at LANL were estimated in the Draft Consolidation EIS (DOE 2005a) to result in generation of about 13 cubic meters (m^3) of transuranic waste and 150 m^3 of low-level radioactive wastes yearly.

Additional details are available in the following DOE NEPA documentation:

- The *Draft Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to the Production of Radioisotope Power Systems* (DOE 2005a)
- The *Site-Wide Environmental Impact Statement for the Continued Operation of the Los Alamos National Laboratory* (DOE 1999a)
- The *Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication* (DOE 1991)

4.1.5 Environmental Impacts of RPS Operations at INL

The INL would integrate the fueled clads produced at LANL with the GPHS modules and the selected converter assembly (either the MMRTG or SRG converter). INL would perform qualification and acceptance testing of both integrated units.

The activities at INL associated with the Proposed Action would be within the normal scope of operations at the facility. The impacts of these activities at INL on the following areas have been addressed in prior DOE NEPA documents (see citations at end of this subsection). No substantial impacts associated with these activities were determined by DOE within any of these areas.

- Land Use
- Radiological and Non-Radiological Air Quality
- Noise
- Water Resources
- Geology and Soils
- Ecological Resources
- Cultural Resources
- Socioeconomics
- Site Infrastructure
- Waste Management
- Human Health Consequences

Activities associated with the Proposed Action would occur at INL, within existing DOE facilities that: 1) already support the NASA's RPS needs as well as other government agencies, and 2) are subject to existing DOE NEPA documentation which addresses production levels sufficient to include the production of plutonium-238 for NASA. The proposed advanced RPS development actions that would be performed at DOE facilities are the same as for ongoing RPS activities; activities that would be expected to continue whether or not the development of the advanced RPS designs continue or not.

Impacts associated with these activities have been analyzed in previous DOE NEPA documentation, most recently the Draft Consolidation EIS (DOE 2005a). This document has addressed, among others, the impacts of activities associated with domestic production of plutonium-238 (from target fabrication through target irradiation in a nuclear reactor to the extraction of plutonium-238 from the targets), purification and encapsulation of the plutonium into fueled clads, and the assembly and testing of RPS units.

The Draft Consolidation EIS (DOE 2005a) reported that continued national security and space related plutonium-238 operations at INL (the No Action Alternative) would result in very, very small releases (estimated 1.7×10^{-6} person-rem/yr or 3.5×10^{-8} Latent Cancer Fatalities over the 35 year operating life and the maximally exposed member of the public dose of 1.4×10^{-10} rem/yr). The facilities at INL where such operations would occur would handle only fully encapsulated radioactive material and therefore these operations would result in no expected releases and off-site radiological consequences. There would be no other types of radiological releases from RPS nuclear production operations. The radiological impacts to the public from normal RPS-related operations at the INL facilities are well below any regulatory limit applicable to the DOE and are expected to be a very small fraction of the public health impact from sitewide operations. Worker exposures from continued operations were estimated as 1.2 person-rem/yr with an average worker dose of 0.017 rem/yr. These exposure estimates are well below the limits set for occupational exposure.

The Draft Consolidation EIS (DOE 2005a) also reported that the radiological accident risks of continued national security and space related RPS assembly operations at INL would be very small (with a maximum annual cancer risk of 0.0026 for the surrounding population). Radiological risks to workers and the public associated with accidental releases from RPS related activities also are a small contributor to the overall risks associated with operations at the site.

Continued national security and space related RPS assembly operations at INL were estimated in the Draft Consolidation EIS (DOE 2005a) to result in generation of a minimal amount of transuranic waste and 1 m³ of low-level radioactive wastes per year.

Additional details are available in following DOE NEPA documentation:

- The *Draft Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to the Production of Radioisotope Power Systems* (DOE 2005a)
- The *Environmental Assessment for the Future Location of Heat Source/Radioisotope Power System Assembly and Operations Currently Located at the Mound Site* (DOE 2002b)
- The *Programmatic Environmental Impact Statement for Accomplishing the Isotope Production Missions in the United States, including the Role of the Fast Flux Test Facility* (DOE 2000) (66 FR 7877, 69 FR 50180)

Transportation to INL

The overall transportation impact would be based on the total number of shipments of plutonium dioxide for assembling one advanced RPS at INL. Two shipments of encapsulated plutonium-238 from LANL to INL are assumed to be required for fabrication of one MMRTG at INL; one shipment for the SRG. Transportation impacts and the finding of no significant impacts are discussed in a DOE NEPA document (DOE 2002b). The impacts of ongoing and proposed RPS-related transportation activities are also discussed in the Draft Consolidation EIS (DOE 2005a). The radiological accident risk associated with the limited shipments of encapsulated plutonium-238 from LANL to INL would be very small, on the order of 6.99×10^{-8} LCF (DOE 2005a).

4.1.6 Environmental Impacts of Advanced RPS Safety Testing

If the DOE safety analysis process identifies the need for additional safety tests of the response of the MMRTG or SRG under launch or reentry accident conditions, part or full-scale testing of the power system with fuel simulant may be needed. The locations associated with these potential tests have yet to be determined. If tests such as these are needed, then the impacts would be expected to be similar to those evaluated and experienced with the tests performed at Sandia National Laboratory (SNL) in support of the Cassini Mission (DOE 1995). The environmental impacts of these tests, including expected operations and accidents, were described in detail in the EA that was prepared to support testing of the Cassini GPHS-RTG (DOE 1995). This EA indicated that under expected operations, environmental impacts would be limited to the personnel involved in the tests and those impacts would be minimal.

4.1.7 Environmental Considerations Associated with End Use of the Advanced RPS

This DPEIS addresses the environmental impacts associated with the development of the MMRTG and SRG to the point where Qualification Units are fabricated and tested. Use of an

advanced RPS on a NASA mission is a potential end use however, the environmental impacts associated with the use of future flight units (*i.e.*, a mission that includes either of the advanced RPS units) are not within the scope of this DPEIS. Each mission that proposes to use an advanced RPS would be subject to further mission-specific NEPA documentation. The following information is intended to provide some perspective on the environmental impacts associated with the potential use of an advanced RPS on future missions.

The potential environmental impacts associated with normal launches for a mission using either an MMRTG or a SRG would be expected to be the same as, or very similar to, the environmental impacts resulting from normal launches, which have been addressed in previous environmental documentation (*e.g.*, NASA 2005c; NASA 2002a; USAF 2000; USAF 1998). The analyses performed have shown these impacts to be short term in nature and associated primarily with exhaust products and noise. No long-term adverse impacts to air quality near the launch area would be expected from the normal launch of missions with advanced RPSs.

Each mission that proposes to carry an advanced RPS would be the subject of both a NEPA process and a separate and independent nuclear safety launch approval process. The NEPA process for each mission utilizes a mission-specific nuclear risk assessment to evaluate the potential radiological impacts of launch accidents. This risk assessment would consider mission specific factors such as the type of advanced RPS selected, the launch vehicle configuration and reliability, launch-site meteorological conditions, and demographic data (launch area and worldwide) that could influence the risk estimates for a specific mission. No mission-specific risk assessment addressing the use of either advanced RPS has been developed to date.

Mission specific factors that affect the calculated risk include: (1) the protective features of the launch vehicle and the devices containing the radioactive material, (2) the probability of an accident which could threaten the radioactive material, (3) the accident environments, and (4) the amount and type of radioactive material used in a mission. For missions that would use an advanced RPS, many of these factors would be similar to those factors considered in the analyses for missions that used the GPHS-RTG.

The design of the GPHS modules to be used in the advanced RPS will incorporate the same safety features as those used in the GPHS-RTG, with additional material added to the graphite aeroshell. These modifications hold the potential to further reduce the quantity of plutonium that could be released as the result of some accidents. The GPHS modules would continue to be fueled with plutonium dioxide, with the plutonium consisting primarily of plutonium-238.

DOE has spent over 20 years in the engineering, fabrication, safety testing, and evaluation of GPHS modules, building on the experience gained from previous heat source development programs and an information base that has grown since the 1950s. DOE has designed the GPHS to assure that the plutonium dioxide is contained or immobilized (limited movement within the environment if not contained) to the maximum extent practical during all mission phases, including ground handling, transportation, launch, and unplanned events such as atmospheric reentry from Earth orbit (NASA 2002b; NASA 1995).

Accident environments associated with all of the launch vehicles being considered for the missions carrying either an MMRTG or SRG would be expected to be similar to the range of environments that have been analyzed for the earlier NASA missions carrying a GPHS-RTG.

Past analyses considered combinations of environments including thermal and mechanical stress to assess the potential for damage to the radiological material.

The nuclear safety launch approval process, as prescribed in Presidential Directive/National Security Council Memorandum 25, requires that a detailed Safety Analysis Report (SAR), which also includes a mission-specific risk assessment, be prepared and reviewed by an ad hoc Interagency Nuclear Safety Review Panel (INSRP) to provide a separate evaluation of the analysis. The INSRP critically reviews the SAR and prepares a Safety Evaluation Report (SER). The NASA Administrator considers the DOE SAR and the INSRP SER and submits a request for nuclear safety launch approval to the Director of the Office of Science and Technology Policy (OSTP). The OSTP Director is authorized to render approval or forward the matter to the President for a decision.

4.1.8 Environmental Justice

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, directs each Federal entity to consider the impacts of its actions on minority populations and low-income populations within a region of influence. Several DOE and other Federal sites would be used in implementing the Proposed Action. The documents referenced in this DPEIS (*e.g.*, DOE 2005a; DOE 2002b; DOE 2000) for these sites include the activities associated with this R&D effort. As indicated in the referenced NEPA documentation, these activities would have no disproportionately high or adverse human health or environmental impacts on low-income populations or minority populations.

4.2 ENVIRONMENTAL IMPACTS OF THE NO ACTION ALTERNATIVE

Under the No Action Alternative, NASA would discontinue R&D efforts for the development of the two advanced RPS designs, the MMRTG and the SRG. However, NASA would continue to pursue the R&D of alternative radioisotope power systems and power converter technologies (see Section 4.3).

Under the No Action Alternative, NASA would continue to consider the use of the existing RTG technology (the GPHS-RTG) that would be supplied by the DOE. It is estimated that one or two GPHS-RTGs can be assembled from existing inventory to support near term mission needs. For longer term radioisotope power system needs, the GPHS-RTG production line would have to be restarted. At such time, an environmental review may have to be performed. Environmental impacts associated with DOE production of GPHS-RTG flight units have been addressed in existing DOE NEPA documents (*e.g.*, DOE 2002b; DOE 2000; DOE 1999a; DOE 1995; DOE 1993a; DOE 1991) and would be similar to impacts discussed previously in Sections 4.1.3, 4.1.4, and 4.1.5 in this DPEIS.

4.2.1 Environmental Considerations Associated with End Use of GPHS-RTG

The environmental impacts associated with the potential use of a GPHS-RTG are not within the scope of this DPEIS. Missions that could use a GPHS-RTG would be subject to further NEPA documentation, in the form of mission specific EISs. The information provided in Section 4.1.7 addressing the non-radiological and radiological impacts associated with a mission is applicable to a mission that would use a GPHS-RTG and provides some perspective on the environmental impacts associated with the potential use of the GPHS-RTGs on future missions.

4.2.2 Environmental Justice

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, directs each Federal entity to consider the impacts of its actions on minority populations and low-income populations within a region of influence. Several DOE and other Federal sites would be used in implementing the No Action Alternative. The documents referenced in this DPEIS (e.g., DOE 2005a; DOE 2002b; DOE 2000) for these sites include the activities associated with this R&D effort. As indicated in the referenced NEPA documentation, these activities would have no disproportionately high or adverse human health or environmental impacts on low-income populations or minority populations.

4.3 ENVIRONMENTAL IMPACTS OF ADVANCED CONVERTER DEVELOPMENT

The NASA R&D efforts involving power conversion technologies are on-going activities and are addressed under both the Proposed Action and the No Action Alternative as these efforts will continue independent of the decision to be made in this PEIS. Advanced converter development encompasses R&D of radioisotope power converter technologies including R&D into technologies that could be used to improve the MMRTG and SRG. Included in the radioisotope power technology systems research is R&D for small RPSs that are based on the GPHS and the radioisotope heater unit (RHU). The basic research into radioisotope power converter technologies consists of a radioisotope power conversion technology efforts and directed research activities performed by and at NASA facilities.

The radioisotope power conversion technology development is performed as part of NASA Research Announcements (NRAs) and is performed as cooperative efforts between private businesses, educational institutions, NASA research facilities, and national laboratories. These activities are directed toward developing improved converter technologies (for example, improved converter efficiency) that can be used as part of power systems with electric outputs ranging from milliwatts to several hundred watts. These activities are typically small-scale R&D efforts. In addition, NASA will also consider power conversion technologies developed by industry and other organizations independent of NASA's action.

All of the activities identified as part of the radioisotope power conversion technology development effort are performed in existing facilities that require, at most, minimal modification. Some of these activities have been initiated, while additional future NRAs are anticipated. The specific activities and locations associated with these future activities have yet to be determined. These future activities are expected to consist of operations that are similar to those that are either ongoing or have been conducted in the past. This allows for reasonable estimates to be made of the potential impacts of the proposed future activities. Impacts associated with some of the radioisotope power conversion technology development efforts already initiated at various private businesses, educational institutions, NASA research facilities, and national laboratories include (GRC 2004a):

- Discharge of small amounts of solvent vapors and process gases. These releases are within limits established by Federal and State law and local ordinances.
- Storage and use of small quantities (quantities associated with processing a single to a few experimental units) of solvents and chemicals, and generation of minor amounts of hazardous

wastes in support of this effort would be within permitted limits for the facility. Disposal of hazardous wastes is via licensed contractors.

- Use of low-odor materials and hazardous materials and potential venting to the atmosphere of xenon or helium gasses. Emissions would comply with Federal, State and local laws and regulations for: airborne emissions, waterborne effluents, external radiation levels, outdoor noise, solid and bulk waste disposal, and handling and storage of toxic and hazardous materials.

The environmental impacts associated with directed R&D efforts for advanced converter technologies would be limited to minor variations in the quantity of airborne emissions, waterborne effluents, and waste disposal at each of the involved facilities; and subsequently both the short-term and long-term environmental impacts are expected to be minimal (GRC 2003; NASA 2004c). Based on the current activity at GRC for the improvements to SRG technology and the segmented thermoelectric development efforts at the Jet Propulsion Laboratory (JPL), these impacts would be expected to include:

- Minimal or no increase in air emissions as a result of R&D activities and would be within permitted limits,
- No direct or indirect adverse effects would be anticipated on either aquatic or terrestrial ecosystems,
- No direct or indirect impact on water quality would be expected, and
- Minor changes in the employment levels at the facilities and therefore, little or no socioeconomic impacts to the local communities.

Additional details are available in the following documentation:

- Radioisotope Power Conversion Technology Environmental Checklist (GRC 2004a)
- *The Record of Environmental Consideration – Nuclear Electric Power & Propulsion Research & Technology* (GRC 2003)
- *The Categorical Exclusions for MMRTG and SRG Research and Development Activities* (NASA 2004c)
- *The Notice of Intent to Issue a Request for Proposal for Small Radioisotope Power Sources for the Space and Defense Power Systems Program* (DOE 2004)

4.4 CUMULATIVE IMPACTS

Cumulative impacts of interest are associated with the operation of facilities that process the radiological material, plutonium-238. These facilities include the LANL fuel processing facility, TA-55, and the RPS assembly and testing facility at INL. Both LANL and INL are large DOE sites that are involved in a multitude of DOE projects and programs. The advanced RPS development activities are a relatively small part of the overall activities at these sites. Cumulative impacts associated with the activities at NASA facilities are within the operating limits as described in the ERD associated with each of the facilities.

The four documents containing the primary references for the cumulative impacts at DOE facilities at LANL are the:

- *Environmental Impact Statement for the Proposed Relocation of Technical Area 18 Capabilities and Materials at the Los Alamos National Laboratory* (DOE 2002a),

- *Final Environmental Impact Statement for the Chemistry and Metallurgy Research Building Replacement Project at Los Alamos National Laboratory* (DOE 2003b),
- *Site-Wide Environmental Impact Statement for Continued Operation of the Los Alamos National Laboratory (LANL SWEIS)* (DOE 1999a), and
- *Draft Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to the Production of Radioisotope Power Systems* (DOE 2005a).

Impacts associated with the Expanded Operations Alternative presented in the LANL SWEIS provide the baseline for current operations at LANL. The projected incremental environmental impacts of reasonably foreseeable future actions at LANL are presented in the EIS for the Chemistry and Metallurgy Research Building Replacement Project.

The impacts of DOE's national security and space-related RPS operations at LANL have most recently been summarized in The Draft Consolidation EIS (DOE 2005a). The No Action Alternative in that Draft EIS identified the incremental impacts of the ongoing national security and space-related RPS operations. The radiological impacts associated with the total plutonium-238 fuel pellet fabrication operations at LANL, compared to the baseline impacts for the Expanded Operations Alternative in the LANL SWEIS, are: 1.8×10^{-5} person-rem/yr out of the total site impact of 33 person-rem/yr to the general public due to normal operations; 19 person-rem/yr to facility workers out of the total site impact of 833 person-rem/yr to workers; and 1×10^{-9} rem/yr to the maximally exposed member of the public out of the total site impact of 5.44×10^{-3} rem/yr to the maximally exposed member of the public. These impacts from RPS operations at LANL are a small fraction of overall LANL radiological impacts. The RPS-related impacts are also well below the applicable EPA limit of 0.01 rem/yr to the maximally exposed member of the public. Transportation and waste impacts due to RPS operations at RPS are below overall LANL impacts.

Continued national security and space related plutonium-238 fuel pellet fabrication operations at LANL were estimated in the Draft Consolidation EIS (DOE 2005a) to result in generation of about 13 m³ of transuranic waste and 150 m³ of low-level radioactive waste per year.

Activities associated with the RPS operations are a small contributor to the cumulative waste generation impacts:

“The contribution to cumulative waste management impacts from other Proposed Actions at LANL, particularly the overall waste generation at LANL during the next 10 years from the disposition of buildings and environmental restoration efforts, could be large. Construction and demolition wastes would be recycled and reused to the extent practicable. Existing waste treatment and disposal facilities would be used according to specific waste types. Solid wastes would be disposed of at the Los Alamos County Landfill or other appropriate permitted solid waste landfills. Demolition wastes would similarly be disposed of at appropriate facilities.” (DOE 2003b, page 4-79)

The cumulative impacts of DOE's national security and space-related RPS operations at INL have most recently been summarized in the Draft Consolidation EIS (DOE 2005a). The No Action Alternative in that Draft EIS identified the incremental impacts of the ongoing national security and space-related RPS operations on past, present, and reasonably foreseeable actions at INL. The radiological impacts associated with the total RPS assembly operations at INL are:

6.0×10^{-5} person-rem/yr out of the total site impact of 0.35 person-rem/yr to the general public due to normal operations; 1.2 person-rem/yr to facility workers out of the total site impact of 390 to 422 person-rem/yr to workers; and 1.4×10^{-10} rem/yr to the maximally exposed member of the public out of the total site impact of 6.9×10^{-5} rem/yr to the maximally exposed member of the public. These impacts from RPS operations at INL are a small fraction of overall INL radiological impacts. The impacts are also well below the applicable EPA limit of 0.01 rem/yr to the maximally exposed member of the public. Transportation and waste impacts due to RPS operations at INL are below 0.01% of overall INL impacts.

4.5 ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

The adverse environmental effects of implementing the Proposed Action or reactivating the GPHS-RTG manufacturing line, including associated Si/Ge thermocouple production, under the No Action alternative are not expected to be substantial. The development activities associated with the MMRTG and the SRG would take place at government and commercial facilities noted earlier in Section 4.1 (*e.g.*, in California, Washington, Maryland, New Mexico, Idaho, Ohio, and Pennsylvania) and activities involving the use of radioisotopes would be performed at existing DOE sites. The MMRTG and SRG development activities that would take place would be similar to the range of activities that have been ongoing at those facilities. The environmental impacts of these activities are expected to be minor and not substantial, and are expected to be within the envelope of permitted activities at those facilities.

Import and transportation of plutonium dioxide as well as purification and encapsulation of fueled clads at LANL or INL, advanced safety testing of the MMRTG and SRG with radioactive simulants, and assembly and testing of the MMRTG and SRG qualification units have a very low risk of exposures of workers and the public to radioactive releases associated with those activities. Continued plutonium dioxide pellet fabrication for both national security and space related applications at LANL have been estimated to generate about 13 m³ of transuranic wastes and 150 m³ of low-level radioactive wastes per year (DOE 2005a). Plutonium dioxide pellet fabrication for the MMRTG and SRG qualification units would constitute a small fraction those annual levels. There remains a very low residual risk of accidents associated with the production of plutonium dioxide, fabrication of the fueled clads, and testing of the MMRTG and SRG that cannot be completely eliminated.

The R&D activities associated with the MMRTG and SRG converters would take place at the commercial facilities noted earlier in Section 4.1 (*e.g.*, in California, Washington, Maryland, and Pennsylvania) and at NASA's Glenn Research Center in Ohio. The MMRTG and SRG advanced converter activities that would take place would be similar to the range of activities that have been ongoing at those facilities. The environmental impacts of the MMRTG and SRG advanced converter activities are expected to be minor and not substantial, and is expected to be within the envelope of permitted activities at those facilities.

Continued R&D on alternative radioisotope power systems and power converter technologies will continue whether or not the Proposed Action is implemented or the No Action alternative is instituted. These activities take place in NASA, commercial, and university facilities, are similar to ongoing activities at these facilities and do not result in substantial adverse environmental impacts.

4.6 INCOMPLETE OR UNAVAILABLE INFORMATION

While this DPEIS has identified a number of uncertainties associated with this development effort (such as the location of future NRA sponsored activities), there is no incomplete or unavailable information relevant to reasonably foreseeable significant adverse impacts associated with implementation of the Proposed Action or the No Action Alternative.

4.7 RELATIONSHIP BETWEEN SHORT-TERM USES OF THE HUMAN ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

The activities that would take place under the Proposed Action or the No Action Alternative occur primarily at Federal facilities and are not inconsistent with Federal, State, local or tribal land use plans.

The successful completion of the advanced RPS development activity would benefit the U.S. space program. In addition to the localized economic benefits, implementing the advanced RPS missions has broader long-term socioeconomic benefits. These include technology spin-offs (such as: high temperature material advancements, higher reliability control systems for Stirling cycle machines and improved efficiency thermoelectric material(s)) to industry and other space use missions; advancing the unique capability of the U.S. to conduct complex planetary missions (thus facilitating major advances in scientific knowledge and humanity's understanding of nature); and supporting continued scientific and engineering education and research at institutions of higher learning.

4.8 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

An irretrievable resource commitment results when a spent resource cannot be replaced within a reasonable period of time. For the Proposed Action or the No Action Alternative, relatively small quantities of various resources, including energy, fuels, and other materials, would be irreversibly and irretrievably committed. The use of these resources would be associated with the fabrication of the MMRTG, SRG, or the GPHS-RTG.

The total quantities of other materials used in the development and production of the MMRTG, SRG, or the GPHS-RTG for future NASA space missions that would be irreversibly and irretrievably committed are relatively minor and may not be irretrievable until the device is used on a mission. Typically, these materials include steel, aluminum, titanium, molybdenum, plastic, glass, nickel, chromium, lead, zinc, and copper. Less common materials may include small quantities of iridium, beryllium, silver, mercury, gold, rhodium, gallium, germanium, niobium, platinum, plutonium, and tantalum.

4.9 ENVIRONMENTAL COMPLIANCE AT ADVANCED RPS DEVELOPMENT, FABRICATION, ASSEMBLY, AND TEST SITES

As part of the NEPA process, an EIS must consider whether actions described under its alternatives would be in compliance with Federal requirements or require Federal permits, licenses, or other entitlements.

In implementing the Proposed Action or the No Action Alternative, all facilities would have to comply with applicable Federal, state, and local rules, regulations, and ordinances to meet with the requirements, standards, and guidelines; for example, air emissions, effluent discharges, solid

and hazardous waste disposal, and noise abatement. Process products such as air emissions, effluents, and waste generation are not expected to require new or additional permitting or licensing and would be disposed of accordingly. Required permits are currently in place at these facilities to support the advanced RPS effort.

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5 LIST OF PREPARERS

The National Aeronautics and Space Administration's (NASA) Science Mission Directorate prepared this Draft Programmatic Environmental Impact Statement (DPEIS) for the development of advanced Radioisotope Power Systems (RPS). As a cooperating agency, the U.S. Department Energy (DOE) has contributed expertise in the preparation of this DPEIS. The organizations and individuals listed below contributed to the overall effort in the preparation of this document.

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This Draft Programmatic Environmental Impact Statement (DPEIS) for the development of advanced Radioisotope Power Systems (RPS) is available for review and comment by Federal, State, and local agencies, and the public. The public review and comment period will close 45 days from the publication of the Environmental Protection Agency's (EPA) *Federal Register* notice of availability (NOA) or NASA's NOA, whichever is later. Timely comments will be considered during the preparation of the Final PEIS. NASA has mailed copies of the DPEIS directly to agencies, organizations, and individuals who may have interest in environmental impacts and alternatives associated with the development of RPSs.

Federal Agencies

Council on Environmental Quality
Federal Emergency Management Agency
National Science Foundation
Office of Management and Budget
U.S. Dept. of Agriculture
U.S. Dept. of the Air Force
U.S. Dept. of Commerce
 National Oceanic and Atmospheric Administration
U.S. Department of Energy
 Idaho Operations Office
 Los Alamos National Laboratory
U.S. Dept. of Health and Human Services
 Centers for Disease Control and Prevention
 National Cancer Institute
U.S. Dept. of the Interior
 Fish and Wildlife Service
 National Park Service
U.S. Dept. of State
U.S. Dept. of Transportation
 Federal Aviation Administration
 Research and Special Programs Administration
 U.S. Coast Guard
U.S. Environmental Protection Agency
U.S. Nuclear Regulatory Commission

State Agencies

State of Florida

East Central Florida Regional Planning Council
Florida Department of Environmental Protection
Florida State Clearinghouse
State of Florida, Office of Governor

State of Idaho

State of Idaho, Office of Governor
Idaho Department of Environmental Quality
INL Oversight Program

State of New Mexico

State of New Mexico, Office of Governor
New Mexico Environment Department

State of Ohio

State of Ohio, Office of Governor
Ohio Environmental Protection Agency
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State of California

State of California, Office of Governor
California State Clearinghouse

State of Maryland

State of Maryland, Office of Governor
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County Agencies

State of Florida

Brevard County
 Board of County Commissioners
 Comprehensive Planning Division
 Economic Development Commission of Florida's Space Coast
 Natural Resources Management Office
 Office of Emergency Management
 Planning and Zoning Office
 Public Safety Department
Lake County
Orange County
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State of Idaho

Butte County
Bingham County
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Bannock County

State of New Mexico

Los Alamos County

Santa Fe County

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State of Ohio

Cuyahoga County

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Local Agencies

State of Florida

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Global Resource Action Center for the Environment
Global Security.org
Greenpeace International
Interhemispheric Resource Center
Indian River Audubon Society
INEEL Oversight Program
Los Alamos Study Group
The Mars Society
National Audubon Society
National Space Society
National Tribal Environmental Council
National Wildlife Federation
Natural Resources Defense Council
The Nature Conservancy
Nuclear Watch of New Mexico
The Planetary Society
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7 INDEX

A

Abbreviations, xix
Aberdeen Proving Ground (APG), viii, 2-4, 3-16
Accident, 2-26, 2-27, 2-28, 4-11

- consequences of, 4-1, 4-2, 4-5, 4-6, 4-8
- environment, 4-1, 4-11
- radiological, 4-7, 4-9

Acronyms, xix
Advanced Radioisotope Power Systems (RPS), v, 1-1, 2-1, 3-1, 4-1, A-1
Advanced Test Reactor, 1-6
Affected Environment, 3-1, A-1
Agencies and Individuals Consulted, 6-1
air quality, 3-4, 3-9, 3-13, 3-17, 3-21, 3-24, 3-25, 4-10
Alternatives, vii, 2-1, 2-18,

- comparison of, 2-25, 2-26, 2-29
- Considered but not Evaluated Further, 2-22
- No Action, viii, x, 1-5, 2-1, 2-18, 2-25, 2-26, 2-29, 4-1, 4-11

Argonne National Laboratory-West (ANL-W), 1-5, 3-8

B

biological resources, 2-29, 3-5, 3-10, 3-14, 3-19, 3-23, 3-26
birds, 3-6, 3-10, 3-14, 3-19, 3-23, 3-26

C

Cape Canaveral Air Force Station (CCAFS), 1-6
Clean Air Act (CAA), 3-4, 4-3
Clean Water Act (CWA), 4-3, 4-4
climate, 3-3, 3-8, 3-13, 3-17, 3-21, 3-24

- regional, 3-24

commercial facilities, 2-27, 3-2, 3-27, 3-28, 4-15

- Infinia Corporation, 2-15, 3-2, 3-28, 4-4
- Lockheed Martin Commercial Space, 3-28, 4-4
- Lockheed Martin Space Systems Company, 2-15, 3-28, 4-4
- Pratt & Whitney Rocketdyne, 2-13, 2-14, 3-2, 3-27
- Teledyne Energy Systems, 2-13, 2-14, 3-2, 3-27, 4-3

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 3-11

Contributors, 5-1

criteria pollutants, 3-4

critical habitat, 3-10, 3-26

cultural resources, 3-20

Cumulative impacts, 4-13

D

dBA, 3-5, 3-9, 3-14, 3-22, 3-26

Department of Energy

see U.S. Department of Energy

dose, 2-26, 3-7, 3-12, 3-16

- public, 2-26, 2-27, 3-7, 3-16, 4-5, 4-7, 4-8
- worker, 2-26, 2-27, 3-8, 3-12, 4-5, 4-7, 4-9

E

endangered species, 3-6, 3-10, 3-14, 3-19, 3-23, 3-26

Environmental Consideration of End Use, 4-10, 4-12

Environmental Compliance, 4-17

Environmental Effects, 4-15

Environmental Justice, 4-11, 4-12

environmental impacts, viii, 2-16, 2-18, 2-25, 4-1

F

floodplain, 3-4, 3-9, 3-21

fuel simulant, viii, 2-4, 2-27, 3-12, 3-16, 4-2, 4-9

G

General Purpose Heat Source (GPHS), v, 1-1, 2-1, 3-3, 4-1, A-2

geology, 2-29, 3-5, 3-10, 3-14, 3-18, 3-22, 3-26

Glenn Research Center (GRC), viii, 2-15, 2-21, 2-22, 3-2, 3-20, 4-4, 4-13, 4-15

Glossary, A-1

groundwater, 3-5, 3-7, 3-13, 3-15, 3-18, 3-22, 3-25, 3-27

H

hazardous waste, 2-29, 3-6, 3-11, 3-15, 3-18, 3-20, 3-24, 3-25, 3-27, 3-28, 4-13, 4-17

I

Idaho National Laboratory (INL), viii, 1-5, 2-4, 2-14, 2-25, 2-26, 2-27, 2-28, 2-29, 3-2, 3-8, 4-1, 4-6,

Incomplete or Unavailable Information, 4-16

Irreversible and Irretrievable, 4-16

J

Jet Propulsion Laboratory (JPL), viii, 2-14, 2-21, 2-22, 3-2, 3-24, 4-13

K

Kennedy Space Center (KSC), 1-6

Kirtland Air Force Base (KAFB), 3-12,

L

land use, 2-29, 3-3, 3-8, 3-12, 3-16, 3-20, 3-24, 4-16

Los Alamos National Laboratory (LANL), vii, 1-4, 2-3, 2-16, 2-17, 2-19, 2-25, 3-1, 3-2, 3-3, 4-1, 4-5, 4-13

M

Materials and Fuels Complex (MFC), 3-8,

Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), v, 1-1, 2-1, 3-1, 4-1

N

National Aeronautics and Space

Administration (NASA), iii, 1-1, 2-1, 3-1, 4-1

National Ambient Air Quality Standards (NAAQS), 3-4

National Environmental Policy Act (NEPA), iii, 1-1, 2-1, 3-1, 4-1

National Pollutant Discharge Elimination System (NPDES), 3-4, 3-9, 3-13, 3-21, 3-25

National Priorities List (NPL), 3-11, 3-20, 3-27

NASA Research Announcements (NRA), 2-19, 4-12, 4-16

No Action Alternative, viii, x, 1-5, 2-1, 2-18, 2-25, 2-26, 2-29, 4-1, 4-6, 4-11
noise, 3-5, 3-9, 3-14, 3-18, 3-22, 3-25, 3-28, 4-10, 4-13, 4-17

Notice of Availability (NOA), xi

Notice of Intent (NOI), xi, 1-4

O

Oak Ridge National Laboratory (ORNL), 1-6, 4-6

P

particulate matter, 3-4

plutonium dioxide (Pu-238), ix, 1-6, 2-5, 2-6, 3-1, 3-3, 3-7, 4-1, 4-2, 4-5, 4-6, 4-15

population, 2-26, 3-4, 3-6, 3-11, 3-13, 3-15, 3-16, 3-19, 3-23, 3-27, 4-5, 4-7, 4-9

Proposed Action, v, 1-2, 2-1, 3-1, 4-1

- description of, 2-2
- nonradiological consequences of, 2-29
- potential radiological consequences of, 4-8
- purpose of, v, 1-2

Purpose and Need for Action, v, 1-1

Q

Qualification Unit, 2-9, 2-14, 2-15, 2-16, 2-17, 4-1, 4-5, 4-6, 4-10

R

Radioactive Liquid Waste Treatment Facility (RLWTF), 3-7
radioactive waste, 2-26, 2-27, 2-29, 3-6, 3-7, 3-11, 3-15, 3-27, 4-9, 4-14, 4-15
Radioisotope Thermoelectric Generator (RTG), v, 1-1, 2-1, 4-1,
References, 8-1
Resource Conservation and Recovery Act (RCRA), 3-7, 4-3, 4-4

S

safety testing, viii, 2-4, 2-18, 3-1, 3-12, 3-16, 4-2, 4-10, 4-15
Sandia National Laboratory (SNL), viii, 2-4, 3-12, 4-9
socioeconomics, 2-29, 3-6, 3-11, 3-15, 3-19, 3-23, 3-27, 4-6, 4-8
soils, 3-5, 3-14, 3-18, 3-22
Stirling Radioisotope Generator (SRG), v, 1-1, 2-1, 3-1, 4-1
superfund site, 3-11, 3-20, 3-27

Systems for Nuclear Auxiliary Power (SNAP), vii, 1-1, 2-3, 2-4, 2-5, 2-6, 2-7, 2-9, 2-11

T

Table of Contents, xii
threatened or endangered species, 3-6, 3-10, 3-14, 3-19, 3-23, 3-26
transportation, ix, 2-18, 2-26, 3-6, 3-7, 3-9, 3-12, 3-14, 3-15, 4-5, 4-9, 4-11, 4-15

U

U.S. Army, 3-1, 3-20
U.S. Department of Defense (DoD), 3-23
U.S. Department of Energy (DOE), v, 1-1, 2-1, 3-1, 4-1
U.S. Department of Transportation (DOT), 3-7, 3-12, 3-15
U.S. Environmental Protection Agency (EPA), v, 3-9, 3-11, 4-14, 4-15

V

Vandenberg Air Force Base (VAFB), 1-6

W

water, 2-29, 3-4, 4-3

- groundwater, 1-4, 3-5, 3-7, 3-13, 3-15, 3-18, 3-22, 3-25, 3-27
- quality, 3-17, 3-18, 4-3, 4-4, 4-13
- storm water, 3-4, 3-9, 3-21, 3-25
- surface water, 3-4, 3-9, 3-11, 3-17, 3-21, 3-25

wastewater, 3-4, 3-7, 3-8, 3-9, 3-18, 3-21, 3-25, 3-27
wetlands, 3-5, 3-6, 3-17, 3-19, 3-21, 3-25

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APPENDIX A

GLOSSARY OF TERMS

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APPENDIX A: GLOSSARY OF TERMS

acceptance testing—A program of measurements and operational tests (under a variety of environmental conditions) that confirm an equipment item (*e.g.*, **RTG**) meets flight requirements.

accident environment—Conditions resulting from an accident scenario, such as blast overpressures, fragments, and fire.

Advanced Radioisotope Power Systems (RPSs)—Two new **RPS** units, the **Multi-Mission Radioisotope Thermoelectric Generator** and the **Stirling Radioisotope Generator**, that use **GPHS** modules as the heat source.

affected environment—A description of the existing environment that could be affected by the Proposed Action or its alternatives.

alpha particle—A positively charged particle ejected from the nuclei of some radioactive elements. It is identical to a helium nucleus consisting of two protons and two neutrons and has a mass number of 4. It has low penetrating power and a short range (a few centimeters in air).

ambient air—The surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures. (It is not the air in the immediate proximity of an emission source.)

attainment—An area is designated as being in attainment by the U.S. EPA if it meets the **National Ambient Air Quality Standards (NAAQS)** for a given **criteria pollutant**.

background radiation—Ionizing **radiation** present in the environment from cosmic rays and natural and manmade sources in the Earth; background **radiation** varies considerably with location.

Categorical Exclusion—Documents proposed actions or activities that the agency has designated under NASA **NEPA** regulations at 14 CFR 1216.305(d) as normally having no significant impacts on the human environment, individually or cumulatively.

clad—High-strength metal shell that encapsulates and protects the **plutonium** dioxide to prevent release into the environment.

criteria pollutants—Common and widespread pollutants with air quality standards under the Clean Air Act. There are standards in effect for six criteria pollutants: sulfur dioxide (SO₂), carbon monoxide (CO), particulate matter equal to or less than 10 or 2.5 microns in diameter (PM₁₀ or PM_{2.5}), nitrogen dioxide (NO₂), ozone (O₃), and lead (Pb).

cultural resources—The prehistoric and historic districts, sites, buildings, objects, or any other physical activity considered important to a culture, subculture, or a community for scientific, traditional, religious, or any other reason.

cumulative impact—The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions

regardless of what agency (Federal or non-Federal), organization, or person undertakes other such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

curie (Ci)—A measure of the radioactivity level of a substance (*i.e.*, the number of unstable nuclei that are undergoing transformation in the process of radioactive decay); one curie equals the disintegration of 3.7×10^{10} (37 billion) nuclei per second and is equal to the radioactivity of one gram of radium-226.

decibel (dB)—A logarithmic measurement unit that describes a particular sound pressure quantity to a standard reference value.

dose—The amount of energy deposited in the body by ionizing **radiation** per unit body mass.

dynamic system—A system that has moving parts. In this document, this term is used in reference to the **SRG**.

Engineering Unit—A fully fabricated **MMRTG** or **SRG** unit fitted with electrical heaters simulating radioisotope heat source modules (*e.g.*, **GPHS**) for use in **acceptance testing**.

enhanced general purpose heat module—A **GPHS** module that incorporates safety related design changes intended to improve the survivability of the **fueled clad** during inadvertent reentry (unplanned reentry) and impact accident conditions.

Environmental Assessment (EA)—Documents proposed actions or activities that may possibly have a significant impact on the quality of the human environment. The EA ultimately leads to a decision by a Federal agency to issue either a Finding of No Significant Impact (FONSI) or a Notice of Intent (NOI) to prepare an **EIS**.

Environmental Impact Statement—The National Environmental Policy Act of 1969 requires that federal agencies prepare detailed analyses of any of their proposed actions that significantly affect the quality of the environment. Environmental impact statements (EISs) are the documents that present these analyses.

fueled—In this DPEIS, a fueled unit such as the **MMRTG** or the **SRG** is an **RPS** in which **plutonium** dioxide fuel has been integrated as the heat source.

fueled clad—The combination of ceramicized **plutonium** dioxide fuel pellet and the iridium cladding in which the fuel is encased.

fuel simulant—A ceramic material, traditionally, Urania (uranium dioxide), that is substituted for plutonium dioxide in safety tests to simulate its mechanical properties.

general purpose heat source (GPHS)—A passive heating device (heat source) that uses radioactive decay of non-weapons grade **plutonium** dioxide to provide heat which is converted into electricity. Pu-238 dioxide is fabricated into pellets and encapsulated in an iridium cladding forming a **fueled clad**. The fueled clads are encased in layers of carbon-based material and placed within an aeroshell housing to comprise the complete GPHS module. DOE has made safety related design changes to the GPHS. The step 1 change is the addition of a 0.25 cm (0.1 in) graphite webbing in the center of the module between the graphite impact shells. The step 2 change is an increase in the thickness of

the two module broad faces. A GPHS module that incorporates these step changes is referred to as an enhanced GPHS.

glovebox—Airtight enclosures, vented to a closed filtering system, that separate workers from equipment used to process hazardous material, while allowing the workers to be in physical contact with the equipment; usually constructed of stainless steel and acrylic/lead glass windows with portholes fitted with heavy-duty lead-impregnated gloves.

health effects—Within the context of this document, health effects are defined as the number of additional, or excess, latent cancer fatalities.

isotope—Any of two or more species of atoms of a chemical element with the same atomic number and nearly identical chemical behavior, but with different atomic mass (number of neutrons) or mass number and different physical properties.

latent cancer fatality—A cancer death occurring some time after, and postulated to be due to, exposure to ionizing radiation or other carcinogens.

low-odor material—Use of materials which, when used in small quantities, emits vapors of which are low in odor such that the impacts on the public are small.

maximally exposed individual—A hypothetical person who would receive the maximum predicted dose.

meteorology—The scientific study of atmospheric phenomenon.

micron—A unit of length equal to one-millionth of a meter; also called a micrometer.

mission platform—Generic term to describe an conveyance used to carry out a particular mission, such as a spacecraft, rover or airplane..

Mixed Waste—Mixed waste is waste that contains a hazardous waste component and a radioactive material component. A hazardous waste is either listed under 40 CFR Part 261, Subpart D, and/or exhibits a characteristic described in 40 CFR Part 261, Subpart C. Radioactive material must be classified as source, special nuclear, or byproduct material subject to the Atomic Energy Act of 1954 (AEA) (42 U.S.C. Section 201 *et seq.*)

multi-foil insulation---A sandwich-like package containing alternating sheets of thin molybdenum foil and quartz cloth, designed to thermally insulate components of the GPHS-RTG in order to prevent over-heating and maximize power generated by the thermocouples

Multi-Mission Thermoelectric Generator (MMRTG)—The **MMRTG** is one of two new **advanced RPS** units anticipated under the Proposed Action. The **MMRTG** builds upon spaceflight-proven passive thermoelectric power conversion technology while incorporating improvements to allow extended operation in planetary atmospheres.

National Ambient Air Quality Standards (NAAQS)—Section 109 of the Clean Air Act requires the EPA to set nationwide standards, the NAAQS are national standards for widespread air pollutants. Six pollutants are regulated by NAAQS (see **criteria pollutants**).

National Environmental Policy Act (NEPA)—The National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321 *et seq.*), NEPA was created to ensure federal agencies consider the environmental impacts of their actions and decisions. NEPA requires all federal agencies to systematically assess the environmental impacts of their proposed actions and consider alternative ways of accomplishing their missions in ways which are less damaging to the environment.

occupational dose limit—As applicable to this document, a specific quantity of radiation received by a worker during the normal course of the worker's activities.

oxides of nitrogen (NO_x)—Gases formed primarily by fuel combustion, which contribute to the formation of acid rain. Hydrocarbons and oxides of nitrogen combine in the presence of sunlight to form ozone, a major constituent of smog.

passive system—A system that has no moving parts. In this document, this term is used in reference to the **MMRTG** or the **GPHS-RTG**.

Plutonium-238—An artificially produced **isotope** of plutonium with a half-life of 87.7 years used as a heat source for **radioisotope power systems**. When **plutonium-238** undergoes radioactive decay it emits alpha particles and gamma rays (high-energy, short wave length electromagnetic radiation that require dense material such as lead for stopping).

Qualification Unit—A fully fabricated radioisotope power system (*e.g.*, **MMRTG** or **SRG**) unit fitted with radioisotope heat source (*e.g.*, **GPHS**) for use in design validation testing. Qualification is the demonstration that a system design is suitable for use in space, achieved through extensive testing under conditions more stressful than would be experienced in space. Responses to extremes in temperature, vibration, acoustic noise levels and other environments are typically tested on a demonstration model that is not intended to be flown.

radiation—The emitted particles (alpha, beta (electrons or positrons emitted by certain radioactive nuclei that can be stopped by aluminum), neutrons) or photons (X-rays, gamma) from the nuclei of unstable (radioactive) atoms as a result of radioactive decay. Some elements are naturally radioactive; others are induced to become radioactive by bombardment in a nuclear reactor or other particle accelerator. The characteristics of naturally occurring radiation are indistinguishable from those of induced radiation.

radiation dose—The amount of energy from ionizing **radiation** deposited within tissues of the body; it is a time-integrated measure of potential damage to tissues from exposure to **radiation** and as such is related to health-based consequences.

radioisotope heating unit (RHU)—An established, low power (1 watt_{th}) heat source device that generates heat through the radioactive decay of **plutonium-238**.

radioisotope power system (RPS)— An RPS generates electricity by converting the heat of radioactive decay into electricity. Each RPS consists of two key components; a heat source and a power converter. The RPS units developed by NASA have used **plutonium-238** as the heat source. The power converters on the current generation of NASA RPS units are thermoelectric (**thermocouple**) converters.

radioisotope thermoelectric generator (RTG)—An **RPS** which supplies electrical energy from a heat source (the heat generated by the natural radioactive decay of non-weapons grade **plutonium** dioxide) via a converter consisting of solid state **thermocouples**.

rem—The unit dose representing the amount of ionizing **radiation** needed to produce the same biological effects as one roentgen of high-penetration X-rays (about 200 kilo electron volts (Kev)).

Safe Secure Trailer/Safeguards Transport (SST/SGT)—A special fleet of trucks and trailers DOE uses to safely and securely transport radioisotopes. The SST/SGT includes tie-down equipment, temperature monitoring, fire alarms, and access denial system. The vehicles undergo extensive checks prior to each trip as well as periodic maintenance checks.

Specific Power—Power output (W_e) per unit mass of the power system.

Stirling cryocooler—A device using a **Stirling engine** for thermal control (*e.g.*, instrument thermal control).

Stirling engine—A mechanical closed-cycle device for the conversion of heat energy to mechanical or electrical power by using the temperature difference between the hot end and cold end of a cylinder to alternately heat and expand an enclosed gas and then compress and cool the gas. This work can be used to drive a power piston that provides mechanical power or can be used to power an electrical generator. The Stirling engine used in the **SRG** converts decay heat from the **plutonium-238** in a **GPHS** into the reciprocating motion of a linear alternator, generating AC electric power and then, via an AC/DC converter, generating $55W_e$ of DC power.

Stirling Radioisotope Generator (SRG)—SRG is one of two new **advanced RPS** units anticipated under the proposed action. The SRG uses two **Stirling engines** as power converters, more efficient converters than **thermocouples** therefore using less **plutonium** to generate comparable amounts of electrical power.

thermocouples—Thermocouples in the **RPS** convert heat generated by the **plutonium-238** to electricity. Thermocouples use dissimilar pairs of specific types of electrically conductive materials, known as thermoelectric materials, to produce electricity directly from the temperature difference between the hot and cold sides of the thermocouple.

transuranic—Refers to any element whose atomic number is higher than that of uranium (atomic number 92), including neptunium, **plutonium**, americium, and curium. All transuranics are produced artificially and are radioactive.

Transuranic (TRU) waste—Radioactive waste, not classified as high-level waste, that contains more than 100 nanocuries (3700 becquerels) per gram of alpha-emitting transuranic **isotopes** with half-lives greater than 20 years. TRU waste disposal by shallow landfill burial is not permitted.

watt—The watt (symbol: W) is the international derived unit for power. It is equivalent to 1 joule per second (1 J/s), or in electrical units, 1 volt-ampere (1 V-A).

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